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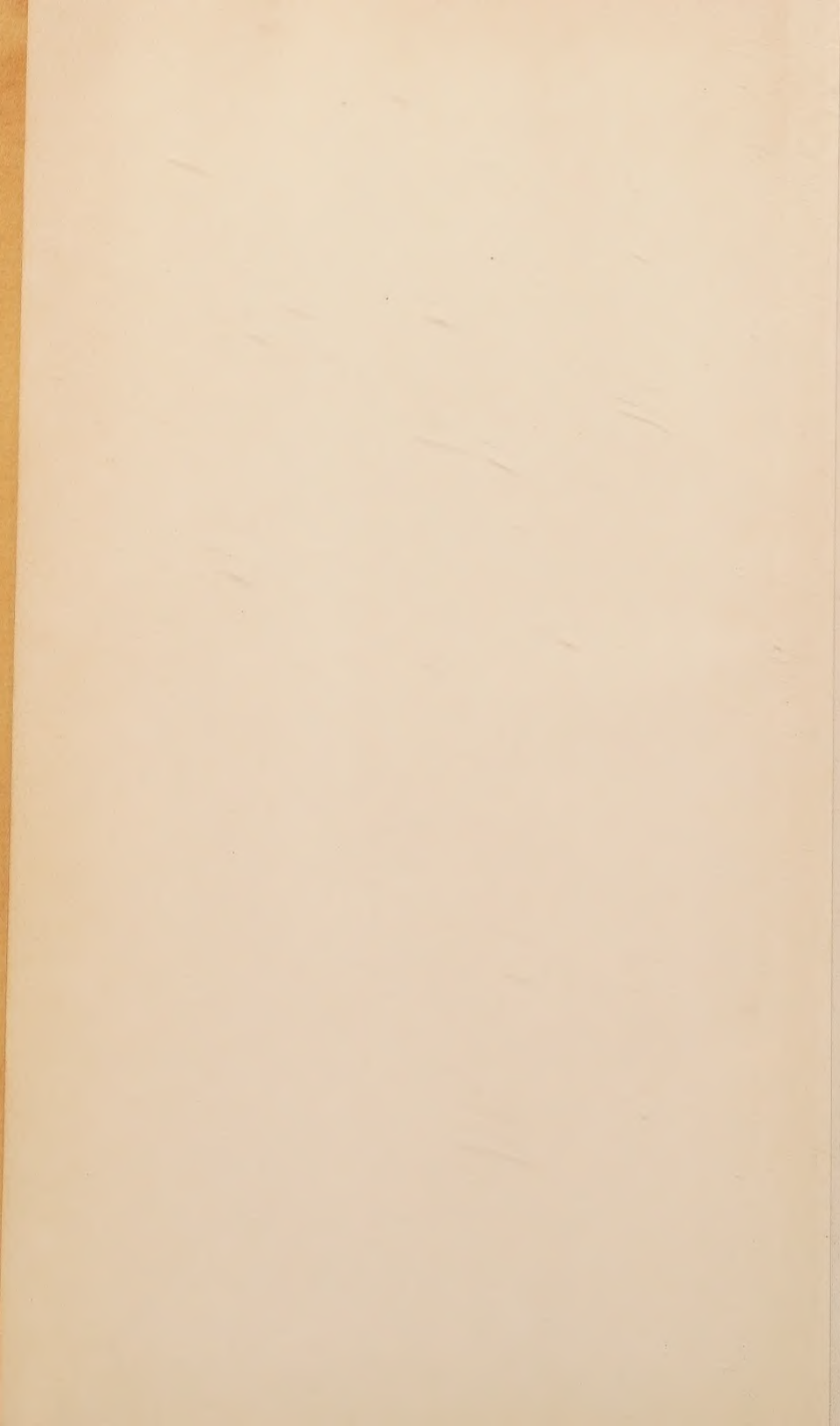
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MARINE AND NAVAL BOILERS

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DEPARTMENT OF ENGINEERING AND AERONAUTICS
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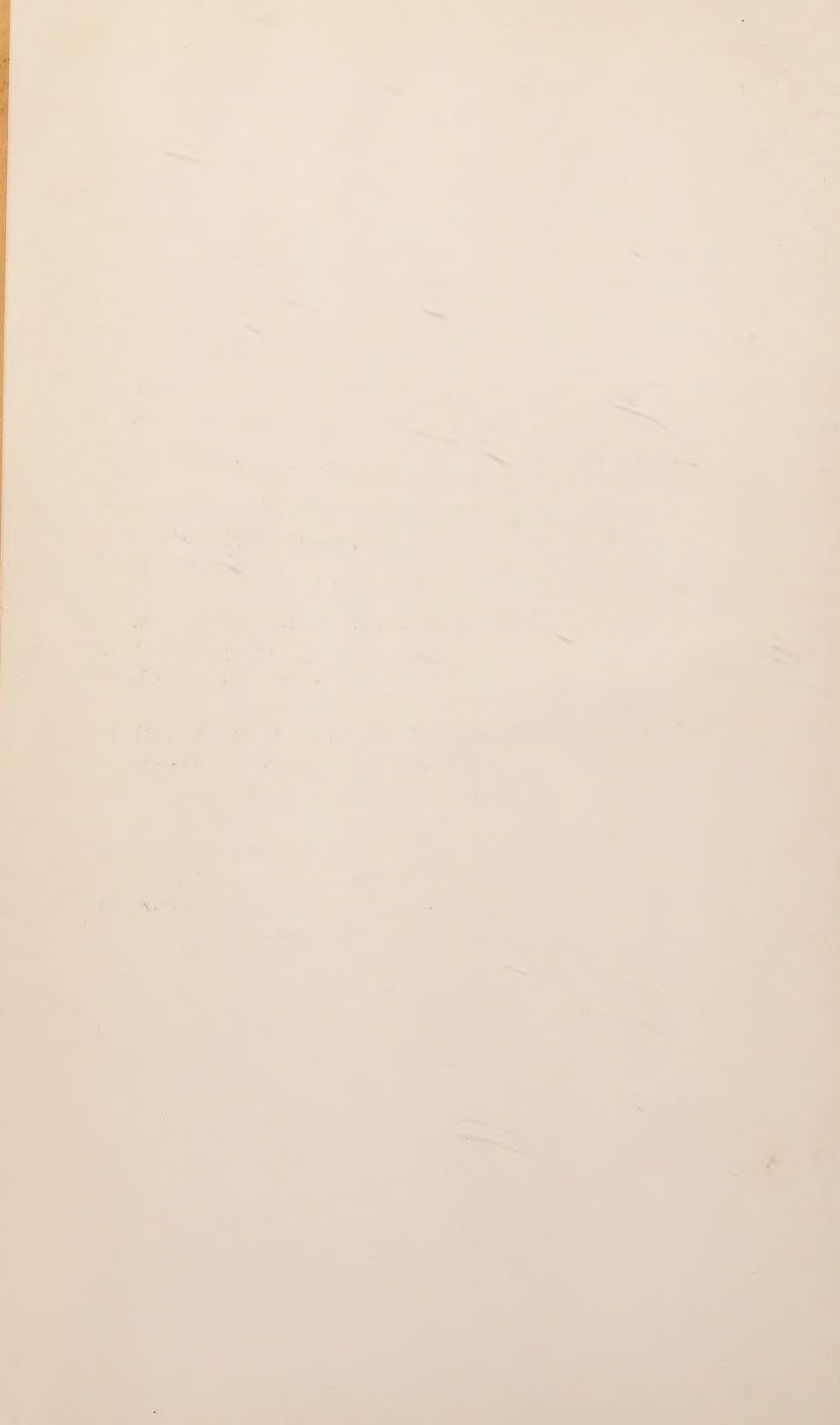


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This book has been compiled by officers of the Department of Engineering and Aeronautics, United States Naval Academy, under the direction of Lieutenant Commander Jay L. Kerley, U. S. Navy, with major assistance by the following officers: Lieutenant Commander H. G. Eldredge, U. S. Navy; Lieutenant W. R. Read, U. S. Navy; Lieutenant C. F. Erck, U. S. Navy; Lieutenant D. L. Jones, U. S. Navy; Lieutenant W. R. Cooke, Jr., U. S. Navy; Lieutenant W. N. Hand, U. S. Navy



PREFACE

The preparation of this textbook was undertaken in order to present to the midshipmen at the Naval Academy, the fundamentals of design and operation of fireroom installations in the U. S. Navy at the present time. Due to the general adoption of small tube water-tube boilers by the Navy Department during the last decade the textbook *Marine and Naval Boilers*, by Lyon and Hinds, was found to be unsuited for modern instruction. With the exception of parts of Chapters VI and X, this text has been entirely rewritten.

It is not intended that this textbook should cover all details of fireroom installations and operation; this text should be used in conjunction with the *Manual of Engineering Instructions*, which should be referred to frequently in the study of this book.

The authors wish to express particular appreciation to the Babcock and Wilcox Company, the Westinghouse Company, and Foster Wheeler Corporation, for their assistance in the preparation of this volume.

G. M. RAVENSCROFT

Commander, U. S. Navy

*Head of Department of Engineering and
Aeronautics.*

3 June, 1929.

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CHAPTER I

DEFINITIONS—PRINCIPLES AND TYPES

A steam boiler is a vessel in which, by the agency of heat derived from the combustion of fuel, water is converted into steam; and in which the steam is raised to the temperature and pressure required for use as the prime mover of machinery.

A marine steam boiler is one adapted to use on board ships.

With few exceptions United States naval vessels are equipped with oil burning boilers.

The heat energy from the hot gases released by the combustion of fuel in the furnace of the boiler is transferred to the water contained in the boiler. The heated water in the form of steam is piped at suitable temperatures and pressure to the proper heat engines which convert the heat energy of the steam, by means of suitable mechanism, into propulsion of the ship, hydraulic, electric, and pneumatic power. Steam is also piped direct to the galleys, heating circuits, fire extinguisher lines, and whistles and sirens.

The efficiency of a boiler really consists of two factors, the efficiency of the furnace and that of the heating surface. The former depends upon a proper proportioning of air and fuel and their intimate mixture to produce perfect combustion. This involves a commodious chamber in which the gases will have space for mixture.

Furnace volume.—The space contained by the boiler structure and casing in which the combustion of fuel takes place.

Heating surfaces are all the metallic surfaces that transmit heat from the flames or gases of combustion to the water. They consist of all the surfaces in contact with flames or gases of combustion on one side and the water containing parts of the boiler on the other. The efficiency of the heating surface depends chiefly upon the proper circulation of the water and hot gases with reference to each other, the greater the absorption of heat the higher the efficiency.

In all cases of measuring the heating surface of a boiler, that to be measured is the surface in contact with the flame or gases of combustion, as for instance, the inside diameter of a fire tube and the outside diameter of a water tube, and not that in contact with the water and steam.

Pressure surfaces or parts are these portions of the boiler which are subjected to the pressure of the steam formed in the boiler.

The general requirements of a good marine boiler are that it should be designed so that it may have as many as possible of the following desired properties :

- (1) All parts readily accessible for cleaning and repair.
- (2) The maximum transfer of heat per unit of heating surface.
- (3) The maximum heating surface in proportion to its weight.
- (4) The minimum of fuel consumed per effective horsepower.
- (5) The maximum strength with minimum thickness and weight of material.
- (6) The maximum ability to stand forcing.
- (7) A constant and thorough circulation of water throughout the boiler.
- (8) Positive circulation of hot gases of combustion in contact with all heating surfaces.
- (9) The minimum of water delivered with steam.
- (10) The minimum radiation losses.
- (11) The maximum resistance to corrosion and erosion.
- (12) The maximum strength due to form without artificial support.

Marine boilers are divided into two general classes: (1) *Fire-tube Boilers*, (2) *Water-tube Boilers*.

In a fire-tube boiler a relatively larger quantity of water is contained in a closed tank or shell. This shell also encloses the furnace, in which the fuel is burnt; the combustion chamber, an enlarged chamber connected to the furnace in which the volatile gases are burnt; and the tubes, through which the hot gases of combustion pass on their way from the combustion chamber to the uptake. All of these parts within the shell are below the water level. This type is called the fire-tube boiler because the hot gases of combustion pass through the tubes. Other names, applied by different authorities to this boiler, are Scotch, shell, tank, and tubular.

Fire-tube boilers.—The two main classes are: (1) *Return Fire-tube Boilers*, (2) *Direct Fire-tube Boilers*.

(1) In the return fire-tube boiler the combustion chamber is considerably higher than the furnace and the tubes connecting the combustion chamber to the uptake are placed above the furnace. Thus the gases of combustion return through the tubes towards the furnace end of the boiler. There may be one or several furnaces. The boiler may be either single ended or double ended; that is, they may have furnaces, combustion chambers, and tubes in one end only or in both ends. Two furnaces are often connected to one large combustion chamber.

(2) The direct fire-tube boiler has its tubes running from the combustion chamber to the uptake at the opposite end from the furnaces. That is, the

gases of combustion run direct in the same direction from furnace to uptake. If the combustion chamber is a separate enlarged chamber, the boiler is said to be of the "gunboat" type. If there is no separate combustion chamber but the upper part of the inner end of the furnace is enlarged to form a combustion space for the volatile gases, the boiler is said to be of the "locomotive" type.

Water-tube boilers.—Boilers of this class have a relatively small quantity of water enclosed in drums or other water spaces, connected by tubes, around which the gases of combustion pass on their way from the furnace to the uptake. Water tube boilers are generally known by the names of their original designers.

Water-tube boilers are classified in two ways: (1) with regard to the size of the tubes; (2) with regard to steam and water circulation.

Size of water tubes.—The large-tube type includes all water-tube boilers having tubes of two inches, or larger, outside diameter, in contact with the furnace or gases of combustion.

The small-tube type includes those water tube boilers which have tubes of less than two inches outside diameter. Small tube boilers, which have a very large amount of heating surface made up of many small, thin tubes, are said to be of the *express type*. The Babcock and Wilcox boiler is the most familiar example of the large-tube type; and the Babcock and Wilcox express boiler of the latter type.

Circulation.—Classed as to circulation, all water tube boilers are of one of the following types:

- (a) *Boilers with limited circulation.*
- (b) *Boilers with free circulation.*
- (c) *Boilers with accelerated circulation.*
- (d) *Boilers with forced circulation.*

(a) Boilers with "limited circulation" have tubes of coil or serpentine form inclined to the horizontal; sometimes they have only a single tube of helical shape surrounding the furnace. There is no circulation except that necessary to replace the water evaporated. The water enters the tubes at the lower end and discharges from the upper end as steam into the steam drum. There are no vertical or nearly vertical legs, headers or other spaces by which the steam bubbles can escape freely into the steam drum; they must travel in the inclined tube through the stagnant water. Boilers of this type are not used in the naval service, and are obsolete also on land.

(b) Boilers with "free circulation" are those in which the generating tubes are slightly inclined to the horizontal and extend between vertical or nearly vertical headers or other water spaces at the front and back or on

the sides. The Babcock and Wilcox (B. & W.) straight-tube boiler is a good example of this type.

(c) Boilers with "accelerated circulation" are those with horizontal drums or reservoirs placed at different heights connected by vertical or nearly vertical tubes. Feed water enters the upper drum or drums, is led to the lower drums by the outside rows of tubes away from the fire or by large tubes called downcomers, unexposed to the furnace. As the water is heated in the tubes the particles of water and the steam bubbles which form in the water flow rapidly up through the inside tubes to the steam drum or drums. The various express types of boilers such as B. & W. Express, Bureau Express (Dyson), Normand, Thornycroft, and Yarrow, are all examples of this type of circulation.

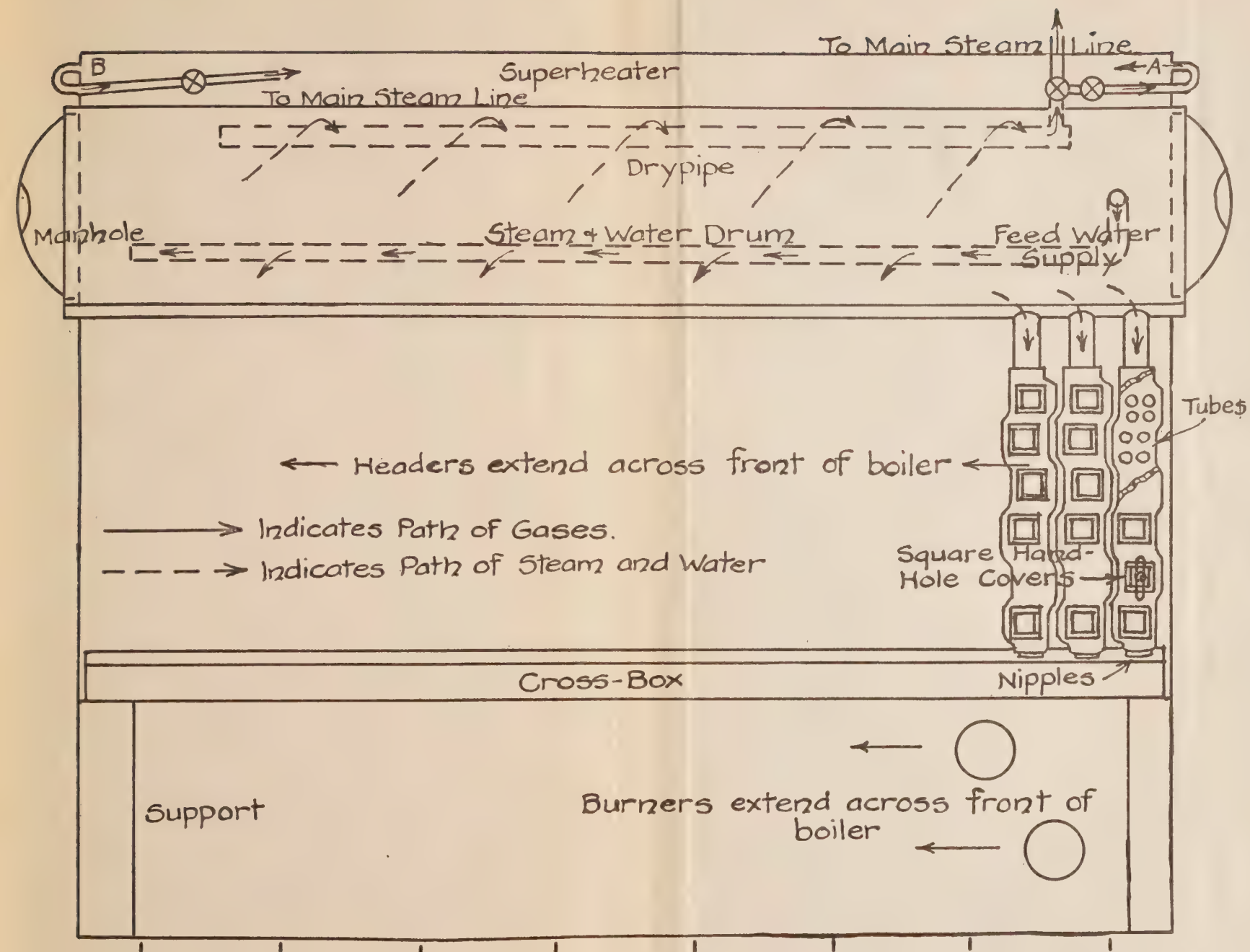
(d) Boilers with "forced circulation" have some external means of pumping the feed water through the boiler. They are not used for naval purposes, as yet.

Comparison of fire-tube and water-tube boilers.—Fire-tube boilers are not adapted to high steam pressures and are not used in high-powered vessels of the Navy. They are still to be found in some auxiliary vessels of the Navy and in many merchant ships and power plants ashore.

The advantages of the fire-tube boiler are: (1) owing to the large volume of heated water and the large steam space, they answer to small fluctuations in speed of short duration with slight attention to fires; (2) as the furnace is enclosed in the shell, there is a smaller radiation loss from the furnace; (3) as the number of tubes is small as compared with the water-tube boiler, there are fewer joints to keep tight; (4) as the volume of water is great, less attention is required to water-tending; (5) as the surfaces containing water are much larger than those exposed to fire and gases of combustion, there is less danger from using salt or impure feed; (6) they are easier to examine and clean.

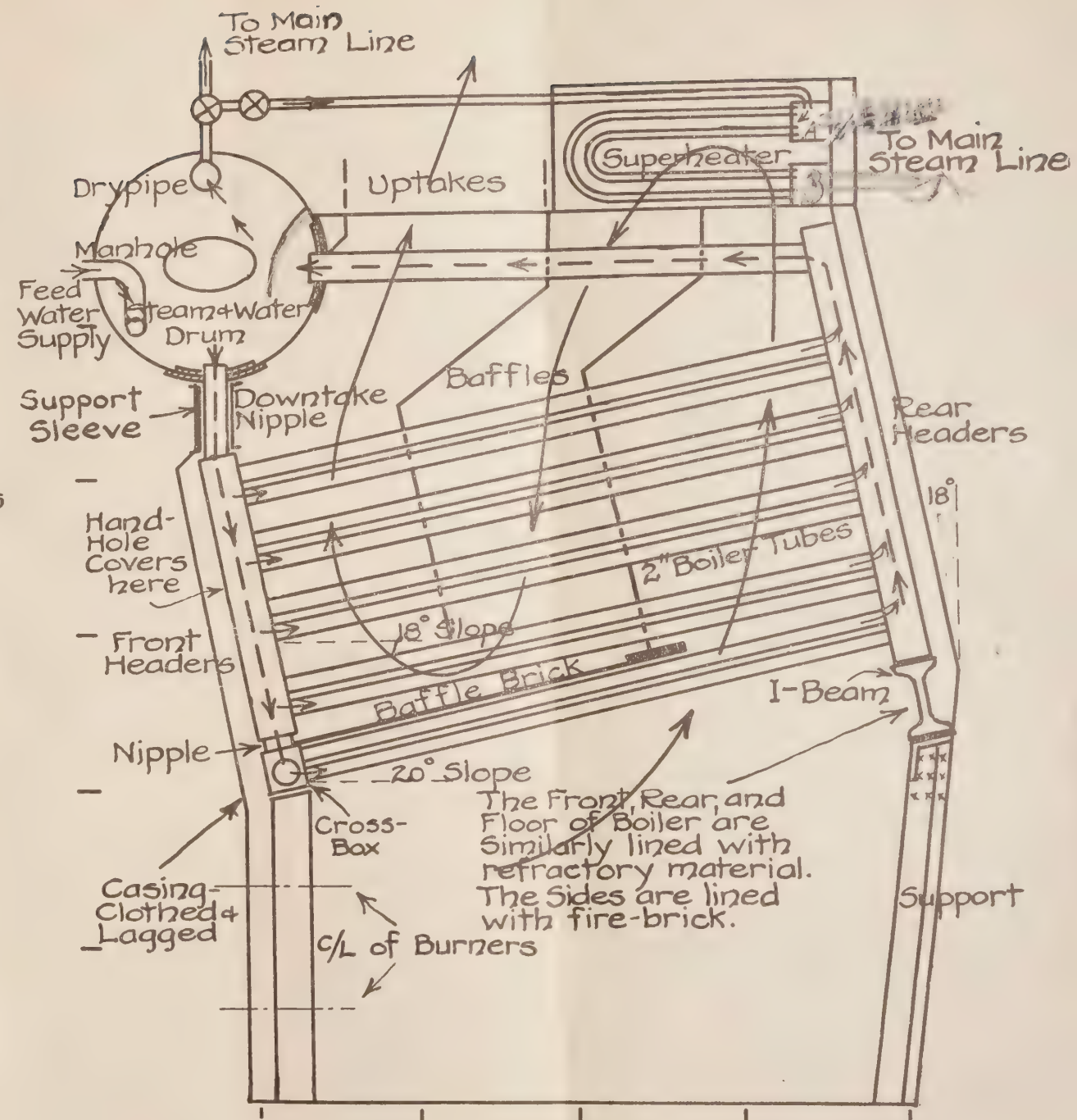
The advantages of the water-tube boiler are: (1) less weight per unit of power generated, (2) less space per unit of power generated, (3) more easily removed from or replaced in a ship, (4) less time and care required in getting up steam, (5) less danger from boiler explosion, (6) greater suitability for high steam pressures, (7) greater ability to stand forcing, (8) less liability to leaks caused by expansion and contraction.

Fire-tube boilers are not being installed in any of the combatant vessels of the U. S. Navy.



Front view.

PLATE II-1.—Outline sketch of B. & W. boiler.



Side view.

CHAPTER II

TYPES OF BOILERS

B. and W. straight-tube oil-burning boiler.—The Babcock and Wilcox Company's straight tube, oil burning boiler is shown in Plate II-1. It is classed as a straight tube, large tube boiler with free circulation.

The steam drum is connected to the front headers by the downtake nipples. A nipple is a short piece of connecting tube. The front headers are connected to the back headers by 2 inch tubes and to the lower front cross box by the cross-box nipples. The front cross box is connected to the back headers by two rows of 2 inch tubes. Each back header is connected to the steam drum by a horizontal 4-inch "circulating tube." All tubes and nipples are secured to headers, drums, boxes, etc., by rolling the joint with a tube expander.

The top supporting sleeves support the steam drum and remove the weight from the drum downtake nipples.

The square handholes in the headers and cross box permit the examination and cleaning of the headers, cross box, and tubes, and the removal and renewal of tubes. There is one handhole in each header for each group of four 2-inch tubes and one handhole in each back header for the 4-inch circulating tube connecting the header to the steam drum. In the front cross box there is a handhole for each group of four 2 inch tubes. The handholes are closed by handhole plates which are fitted with thin asbestos fiber gaskets. The plates are secured in place by dogs.

The front cross box is supported at its ends and middle by vertical supports. The back headers rest on a heavy I beam, held by similar vertical supports. The back headers are free to slide on the upper surface of this I-beam to allow for the expansion and contraction of the tubes. Escape of gases between headers and nipples is prevented by means of asbestos paste and wicking stuffed in to fill those spaces.

The headers are inclined at an angle of 18° from the vertical. The drum downtake nipples are vertical. The 4-inch circulating tubes are horizontal. The 2-inch tubes connecting the front and back headers are inclined at an angle of 18° to the horizontal, and the two rows of 2-inch tubes connecting the front cross box to the back headers are inclined at an angle of 20° to the horizontal. This inclination assists the circulation. The water level

is carried at the middle of the steam drum. All tubes, including the 4-inch circulating tubes are below the water level.

Water and steam circulation.—Feed water enters the steam drum through the main and auxiliary feed stop-and-check valves to the internal feed pipe, which runs the full length of the bottom portion of the drum and is discharged upwards through holes in the upper surface of the internal feed pipe beneath the water level. The feed water, being comparatively cool, sinks from the drum through the downtake nipples to the front headers and front cross box and thence into the 2-inch generating tubes. The water in the 2-inch tubes is heated, rises through the tubes to the rear headers, then rises to the 4-inch circulating tubes, and flows back to the steam drum. Steam bubbles, which have formed in the water en route, rise to the surface of the water in the steam drum and fill the space in the drum above the water level. The baffle opposite the ends of the circulating tubes in the steam drum retards the flow of the steam from the circulating tubes to the steam space and separates entrained water from the steam emerging from the circulating tubes.

The dry pipe, which runs the full length of the drum at the top, has holes cut in its upper surface so that the steam flow is obstructed sufficiently to check carrying over entrained water.

The steam flows from the dry pipe, through a stop valve and pipe to the superheater. In the superheater a series of diaphragms in the two superheater headers direct the steam through the U-shaped tubes which are placed in the path of the rising gases of combustion of the boiler. The steam leaving the superheater is led to the main steam line by a short connecting pipe and a stop valve. A by-pass pipe, fitted with a stop valve, connects the steam pipes leading to and from the superheater, so that the superheater may be cut out and the steam by-passed directly from steam drum to main steam line in case of damage to the superheater. This by-pass is to be used only in case of emergency.

Fire brick roof blocks are laid over the upper row of tubes connecting the front cross box and rear headers, covering the furnace from the front to about two-thirds of the distance toward the back. These roof blocks are of a special shape, hollowed out to fit over and around the tubes, so that they form a solid, gas-tight, inclined baffle over the front part of the furnace. At the back end of this roof-block covering are placed cast-iron baffle blocks. The cast-iron flame plates are placed at right angles to the direction of the tubes and extend from the baffle blocks to the baffle plate which extends down at an angle from the superheater baffle blocks. The flame plate and baffle blocks form a wall between the tubes and direct the gases of combustion up from the back end of the furnace to the super-

heater. Another baffle plate extends downward on an angle from the top of the superheater casing, striking the 4-inch circulating tubes at a distance from their front ends of about a quarter of their length. Another



FIG. II-1.—A photograph of a section of coal-burning B. & W. boiler. It differs from the oil-burning type in many minor details.

row of flame plates extends down, in a plane perpendicular to the direction of the tubes, to about four-sevenths of the depth of the tubes from the top.

Another gas wall is thus formed and the gases of combustion are directed down from the superheater to the bottom of the front flame plates and then up between the flame plates and baffles and the front of the boiler to the uptake, which is connected between the front of the superheater and the steam drum.

The path of the gases of combustion crosses the tubes three times. Nipples on which flame impinges are covered with asbestos pulp.

The casing doors at the front and back of the boiler give access to the handholes in the front and rear headers for cleaning and repairs. The handholes are covered by handhole plates, fitted with gaskets and dogs.

The manhole in the steam drum gives access to the interior for repairs and cleaning. The manhole is secured by a manhole plate fitted with a gasket.

Doors are fitted in the side casings for the insertion of steam lances or compressed-air lances "to blow tubes."

The door in the front casing below the burners gives access to the furnace for cleaning of the fire sides of the tubes and repairing brickwork.

Peepholes are provided above the burners for observing furnace conditions.

Express-type boilers.—Express-type boilers are water-tube boilers with small tubes and accelerated circulation. All express-type boilers now in use in the Navy have drowned tubes, that is, their tubes enter the steam drum below the water level and no parts of the tubes are above the water level. All of the express-type boilers now in use in the Navy are of the inverted V-shape with a large steam drum above and two smaller water drums (often called mud drums) below. The boiler tubes, one inch to one and one-quarter inch in diameter, connect the steam drum with the water drums and are expanded into the tube sheets of the drums, which are given extra thickness where the tubes enter the drums. NOTE: Boiler tubes are quoted by the exact outside diameter, thereby differing from pipes.

Some types of express-type boilers are equipped with *downcomers*, which are large steel tubes from four to six inches in diameter and which connect the front or rear end of the steam drum to the front or rear ends of the water drums and aid the circulation of the water in the boiler by conveying the comparatively cool incoming feed water down from the steam drum to the water drum. In those express boilers which have no downcomers all of the cooler water is led down from the steam drum to the water drum by the outer rows of tubes which are least exposed to the heat of the furnace. Steam bubbles rise in those tubes nearest the furnace.

The furnace of an express-type marine boiler is the space enclosed by the steam drum, tubes, water drums, and the front, back, side, and floor brickwork.

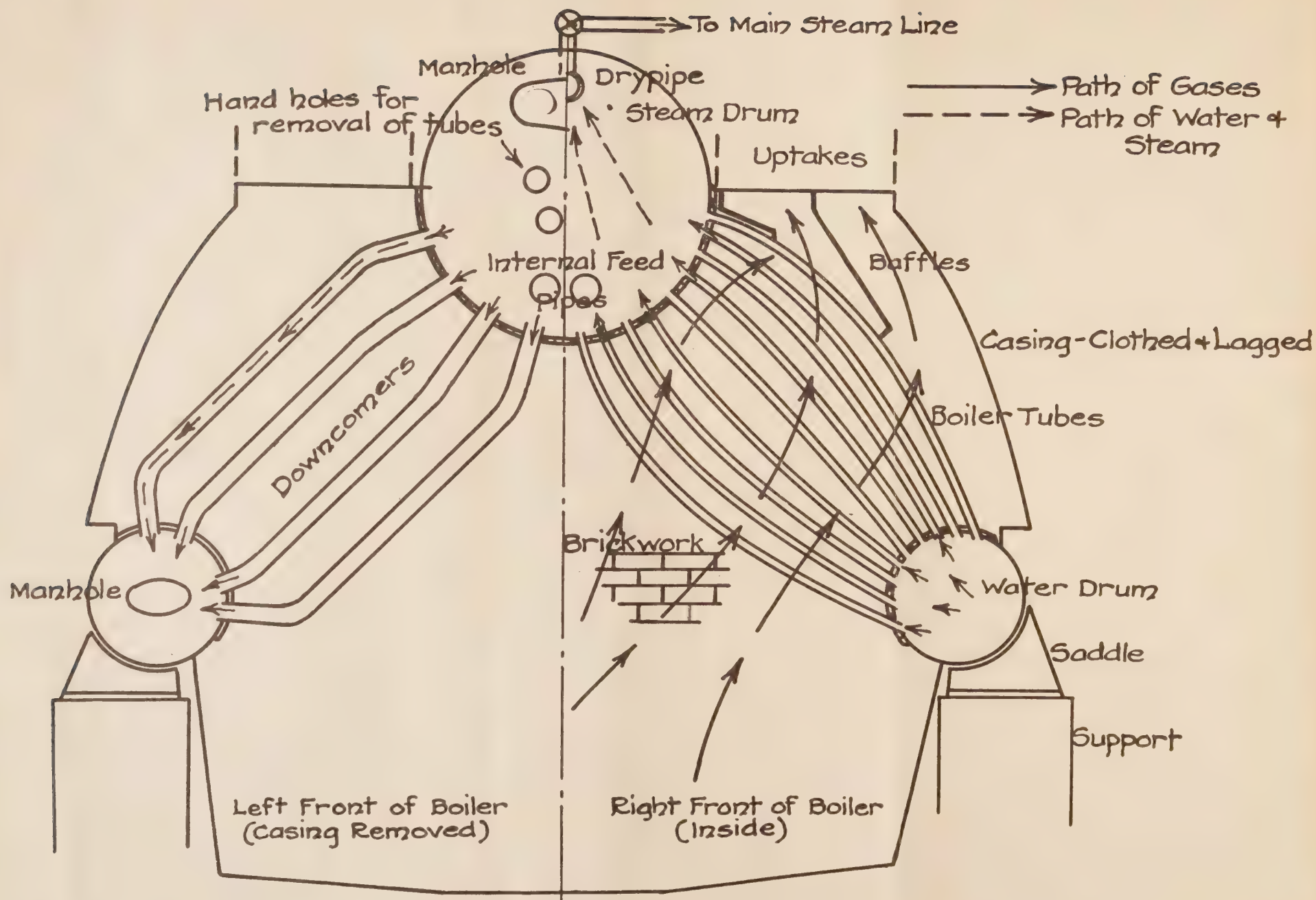
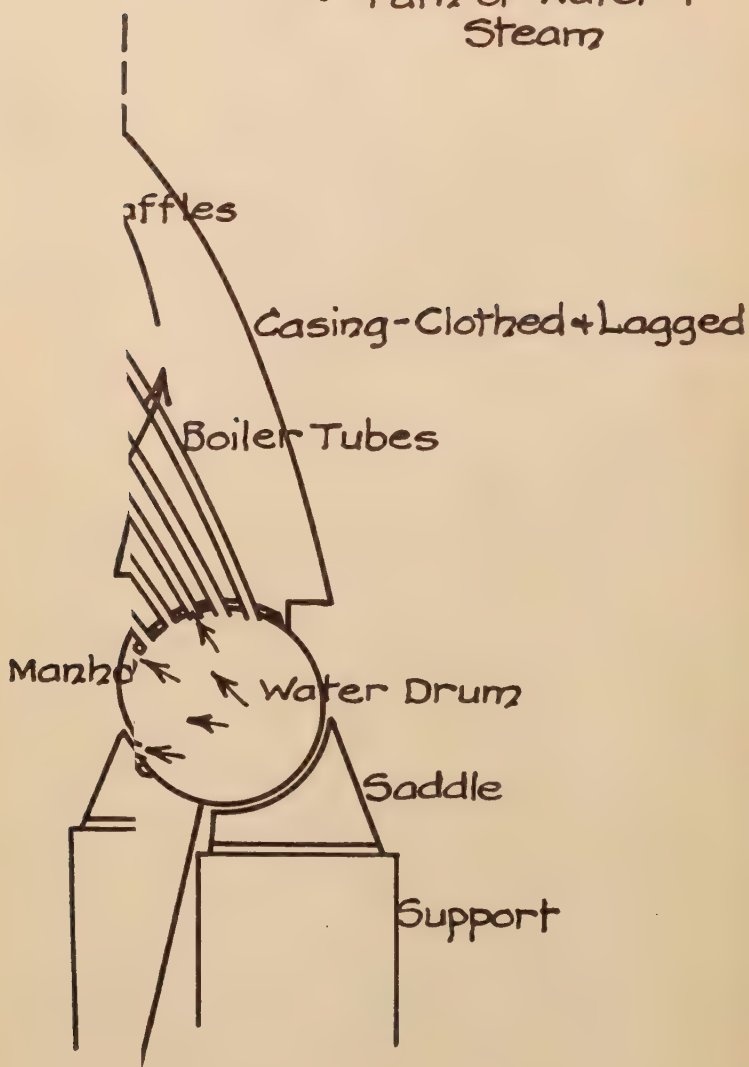


PLATE II-2.—Outline Sketch of B. & W. Express Type Boiler.
Front View.

Line

—————→ Path of Gases

- - - - -→ Path of Water & Steam



The floor, front and back, and the sides of the furnace up to the height of the center of the water drums are lined with fire brick or special refractory brick and insulated with layers of magnesia blocks, and patent insulating materials. Air spaces are built into the brick walls of some types of boilers to insulate the furnace. The cracks between the furnace bricks and the exposed surfaces of the bricks are protected by a wash of refractory cement. The special shaped bricks used in certain parts of some express-type boilers, and the cone bricks in the fronts of oil-burning boilers may be repaired or renewed by building up the worn bricks, or molding new bricks in place, using plastic refractory cement.

The gases of combustion are directed through the tube nests to the uptake by baffles of sheet steel or by tubes spaced so close together that the tubes themselves act as baffles. The object of baffling the gases of combustion is to force the gases of combustion to come in contact with all of the generating tubes and to retard the movement of the gases so as to make them give up as much of their heat to the tubes as possible. When the gases can be made to flow along the tubes a scouring effect is produced which removes the film of comparatively cool gas from the surface of the tubes and ensures a maximum heat transfer from the gases to the tubes. The method of baffling differs for each type of express-type boiler, though based on the single principle of obtaining maximum heat transfer by **retarding and directing the gases of combustion.**

Some express-type boilers are fitted with superheaters which evaporate any moisture carried over with the steam and raise the temperature and heat energy of the steam above that of saturated steam of the same pressure. The method of installation and location of the superheating surfaces differs in each type of express boiler.

B. & W. express-type.—The Babcock and Wilcox Company manufactures the B. & W. express-type boiler, sometimes called the White Forster type.

The model in the model room of Isherwood Hall is a section of a boiler of this type, now installed in several light cruisers.

This boiler is of the usual express-type shape with one large steam drum and two smaller water drums. Figures II-2 and II-3 are front and rear view photographs of this boiler. Plate II-2 is a sketch of the front view.

Four curved downcomers, four inches in diameter, lead from the steam drum to each water drum. These eight downcomers are located between the inner and outer casings of the boiler front and are not exposed to the heat of the furnace. The downcomers aid circulation by conveying the comparatively cool feed water from the vicinity of the internal feed pipe to the steam drum to the water drums.

Each tube is one inch in diameter. In manufacture the tubes are curved in one plane only, and with the same radius of curvature; when placed in the boiler, however, a curvature both towards the furnace and toward one end of the boiler is obtained by slightly revolving the tubes before expanding them into place. In other words, the tube which looks straight in the half-front view is curved in a fore-and-aft plane, being bowed towards the rear as seen in the side view. This arrangement accomplishes the same

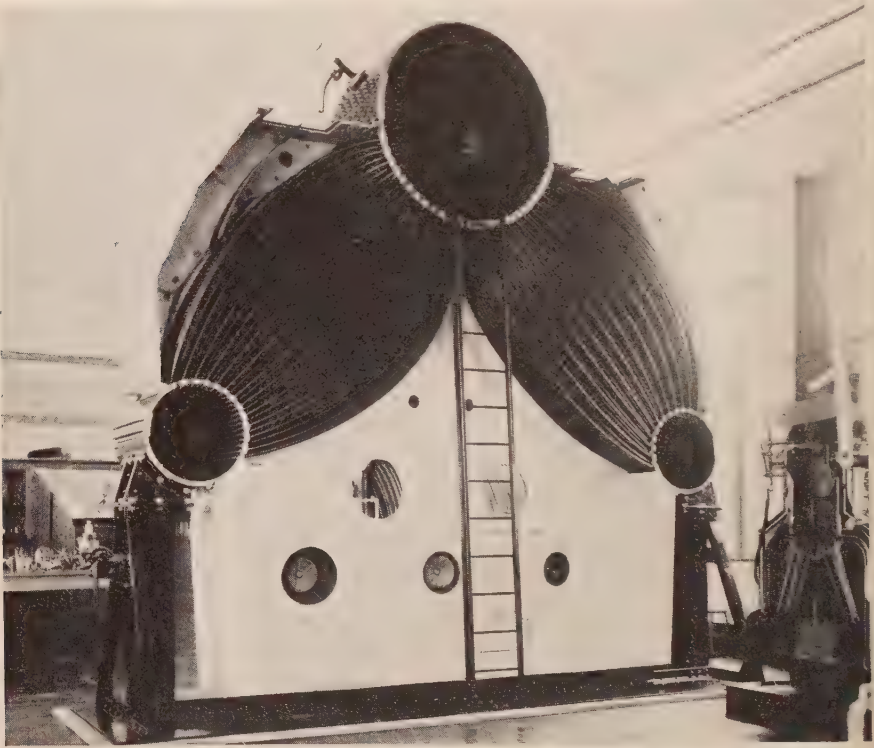


FIG. II-2.—B. & W. Express-type Boiler, Rear View.

result as using tubes of different curvatures and makes it possible for a ship to keep only one kind of spare tubes on hand.

The length and curvature of the tubes and the location of the manhole in the upper part of the front head of the steam drum make it possible to remove or replace nearly all of the tubes through the manhole. A few tubes in the front of the boiler cannot be removed or replaced through the manhole, but eight plugholes in the front head of the steam drum below the manhole are so located as to permit those front tubes to be hauled in or out through the plugholes.

The weight of the boiler is supported by saddles under the water drums. The water circulation is as follows: from the internal feed pipes into the steam drum, down through the eight downcomers at the front of the boiler

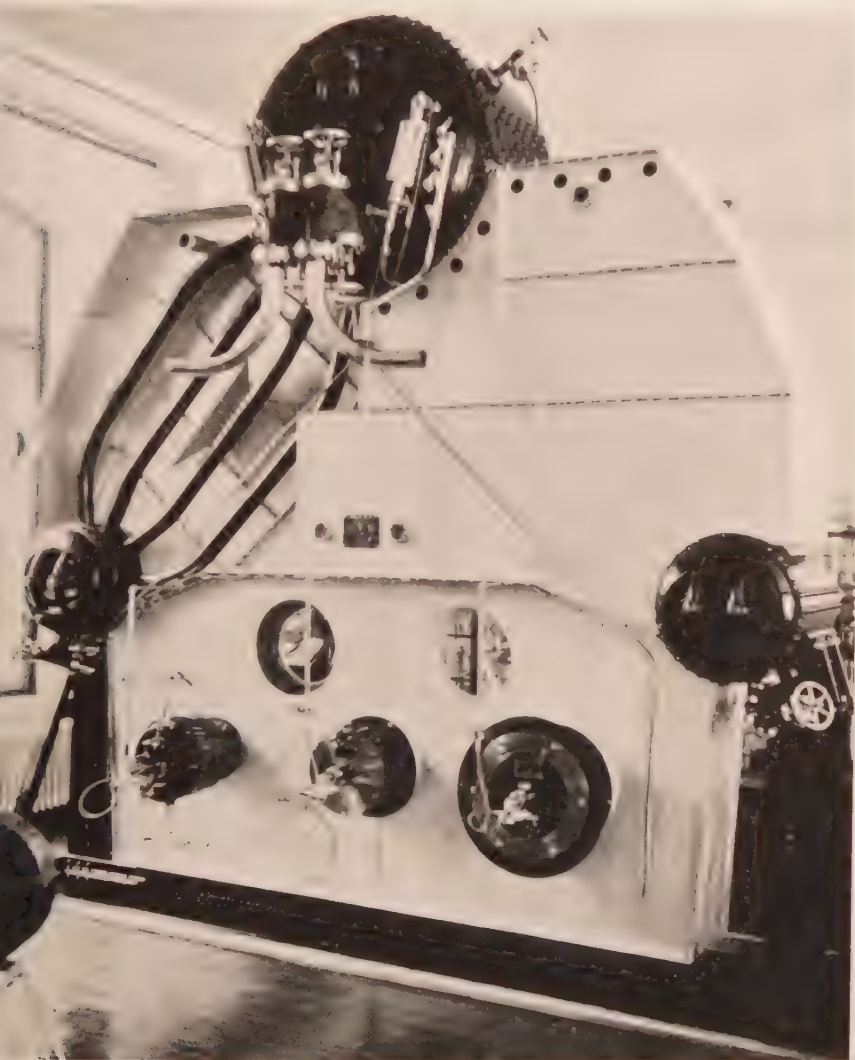


FIG. II-3.—B. & W. Express-type Boiler, Front View.

the water drums, up through the tubes to the steam drum where the steam particles, which have been generated in the tubes, break through the surface of the water, move to the top of the steam drum and flow into the dry pipe through the holes in its upper surface.

The two baffles on each side force the gases of combustion to flow around and along all of the tubes and restrict the gas passages to the uptakes so that the gases come in contact with the lower ends of all tubes instead of flowing directly to the uptake.

In the destroyer-type B. & W. express-type boiler there is only one downcomer on each side. These two downcomers are six inches in diameter and are located at the rear of the boiler. (Plate II-3 is a sketch of this type).

In the B. & W. express-type boilers on some naval vessels there are no downcomers. In these boilers the outer rows of tubes act as downcomers and conduct the cooler water from the steam drum to the water drums. These outer tubes are one and one-fourth inches in diameter; the inner rows or generating tubes are one inch in diameter as in the other B. & W. express-type boilers. These boilers are equipped with superheaters located in the middle of the tube nests. The middle rows of generating tubes are omitted and the U-tubes of the superheaters are run horizontally from the back to the front of the boiler. The superheater boxes are at the back of the boiler and the steam from the dry pipe of the steam drum is led down to a superheater box on each side by steam pipes which run through the bottom of the rear end of the steam drum. The superheated steam is piped from the other two superheater boxes to the main steam line. The superheaters are fitted with cut-out valves and by-passes so that either or both of the superheaters may be cut out and the steam led direct to the main steam line from the dry pipe in case of leaks in the superheater tubes. Plate II-4 shows the arrangement of the B. & W. express-type boiler with superheater and Figure II-4 is a photograph of this boiler. Note the two pipes leading from superheaters to the boiler stop valve and steam line.

Thornycroft boiler.—The Thornycroft boiler has the usual inverted V-shape with 1-inch tubes and one downcomer at each side. The downcomers are at the front of the boiler outside the casing. Each row of tubes has a different curvature.

No baffles are fitted among the tubes. The flow of gases of combustion is direct, being restricted only by a short deflecting plate at the opening to the uptake.

There is an air space between the back brick wall and the casing.

In other respects the Thornycroft boiler is like the other types of express boilers.

The Normand boiler.—The Normand boiler has the usual inverted V-shape with one steam drum and two water drums. There is one downcomer on each side at the back of the boiler and one hollow stay tube on each side at the front of the boiler. The hollow stay tubes serve as small

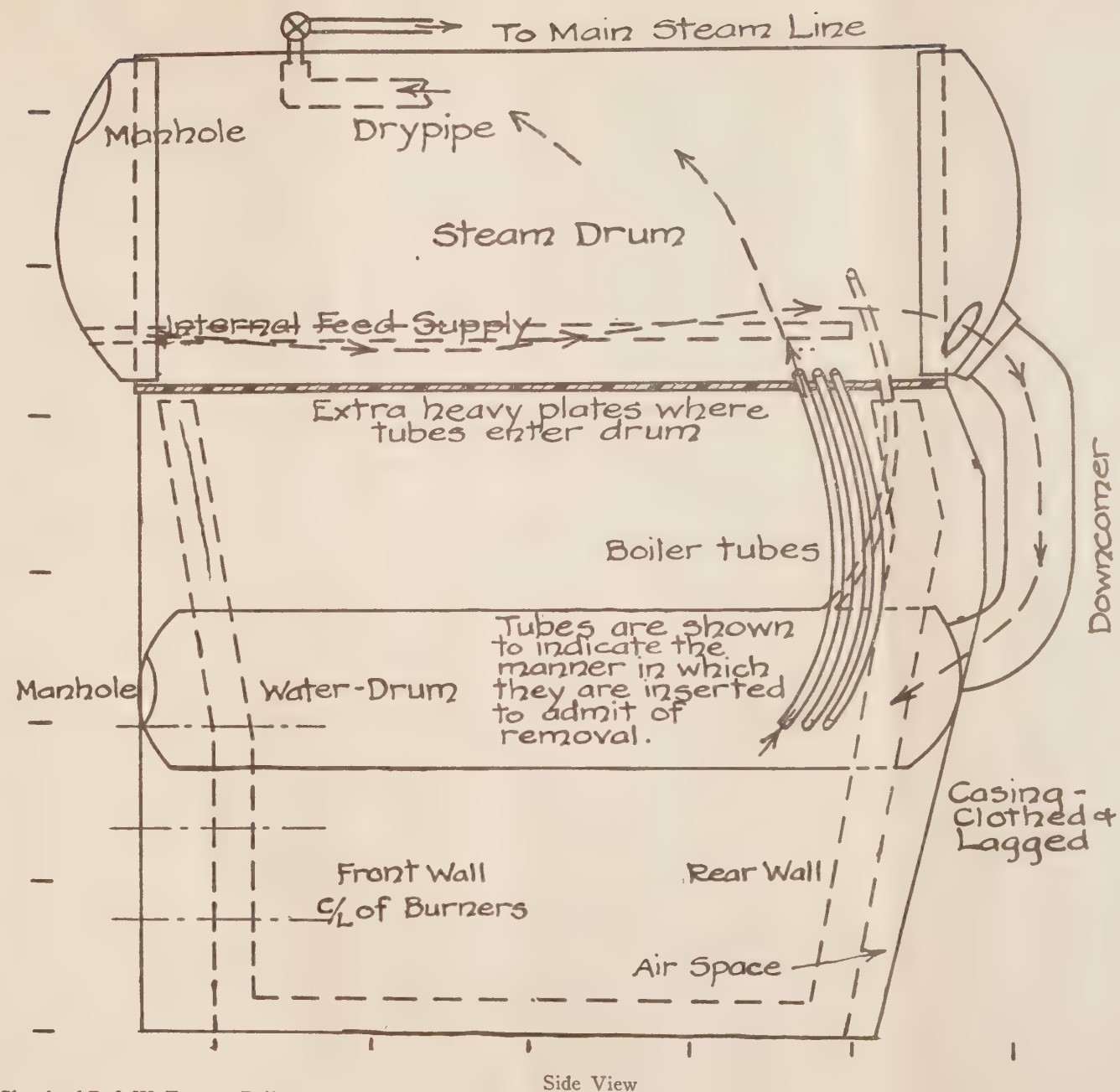
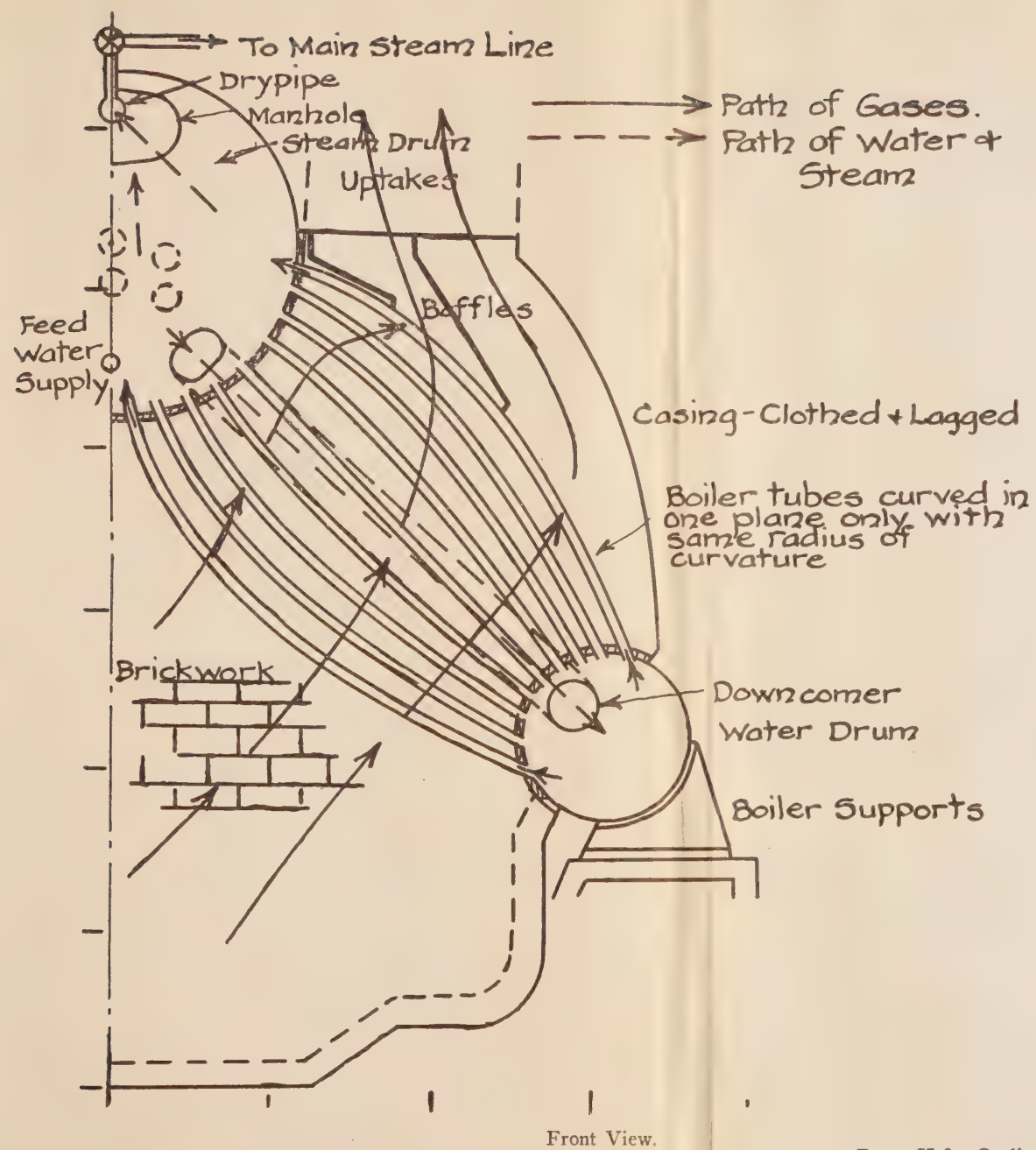


PLATE II-3.—Outline Sketch of B. & W. Express Boiler.



downcomers. The stay tubes and downcomers are outside the boiler casing. A steam dome is riveted to the top of the steam drum at the front. A very short dry pipe is fitted in the steam dome.

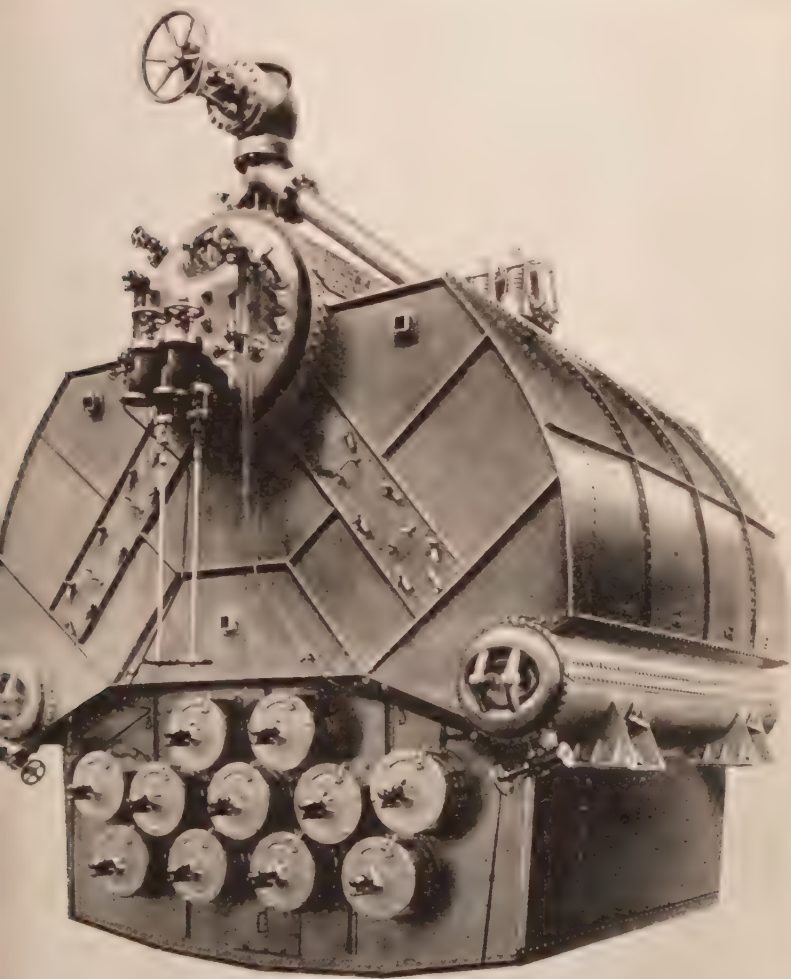


FIG. II-4.—B. & W. Express-type Boiler with Superheater.

The tubes are one inch in diameter and each row has a different curvature. The curvature and spacing of tubes are so designed as to make the walls serve as baffles for the gases of combustion. The two inner rows of tubes are fitted so closely together as to make a tube wall extending

two-thirds of the way from the front to the back of the boiler and the two outer rows form a similar tube wall from the back to the front of the boiler. These outer tubes are so curved as to leave openings between the tubes at the top in the front in way of the uptake. A vertical baffle plate, parallel to the boiler front, extends down about one-third of the way from the top of the boiler, it is located between the tubes, in line with the rear of the uptake, about one-third of the distance from the front to the back of the boiler. The steam drum between the two tube nests at the top of the furnace space, is protected by a row of special refractory bricks.

The path of the gases of combustion is as follows: back through the furnace inside the tube nests about two-thirds of the way to the back of the boiler, between the widely spaced tubes at the rear, back to the front of the boiler between the inner and outer tube walls passing between the staggered tubes of the middle rows, under the lower edge of the vertical baffle plate, and up through the spaces between the tubes of the outer tube wall to the uptake.

In other respects the Normand boiler is similar to the other types of express boilers. Normand type boilers are installed in some United States destroyers and are used extensively in foreign naval vessels.

Bureau express-type boiler—(Dyson design).—The Bureau express-type boiler (Dyson design) is built in two different types: (a) without superheater, as shown in Plate II-5 and (b) with superheater, as shown in Plate II-6. In both types there is a large steam drum and two smaller water drums connected by straight tubes bent at the ends so as to enter the drums on radii. No downcomers are fitted.

Feed water enters the steam drum through the internal feed pipe, passes down to the water drums through the outer rows of tubes, and returns to the steam drum through the inner rows of tubes. The steam particles which have been generated in the tubes break through the surface of the water, move to the top of the steam drum, and flow into the dry pipe through the holes in its upper surface. The water level is maintained just above the highest row of tubes.

In the type without superheater, the gases of combustion are retarded and directed by three sets of baffles on each side. These baffles force a more equal distribution of gases across the tubes rather than following along the tubes in too narrow a stream.

In the type with superheater, the gases of combustion are retarded and directed by the superheater tubes which are curved so as to extend down between the tubes of the main tube nest. The superheater tubes act as baffling and accomplish the same result with regards to the gases of combustion as the baffle plates in the type without superheater.

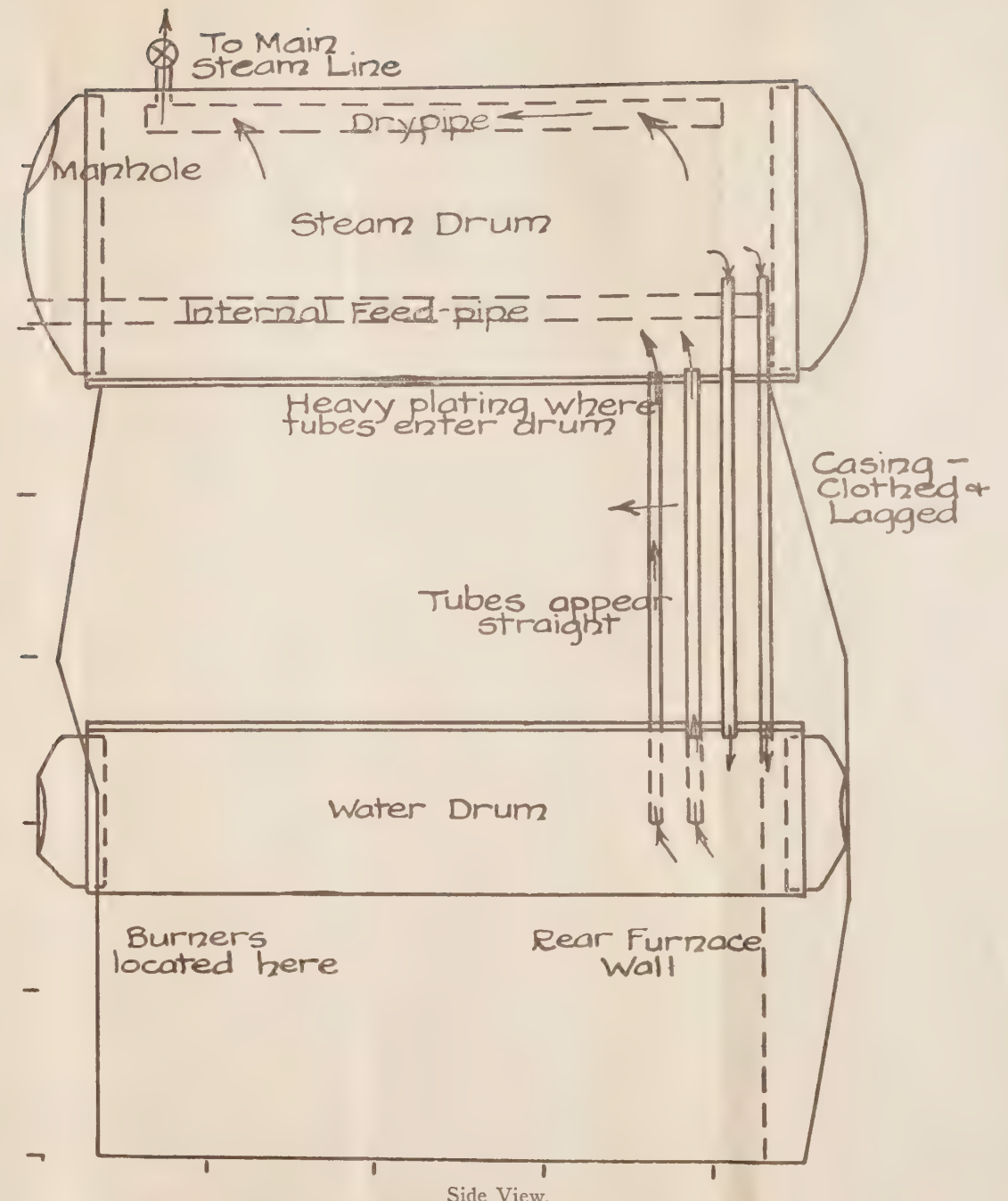
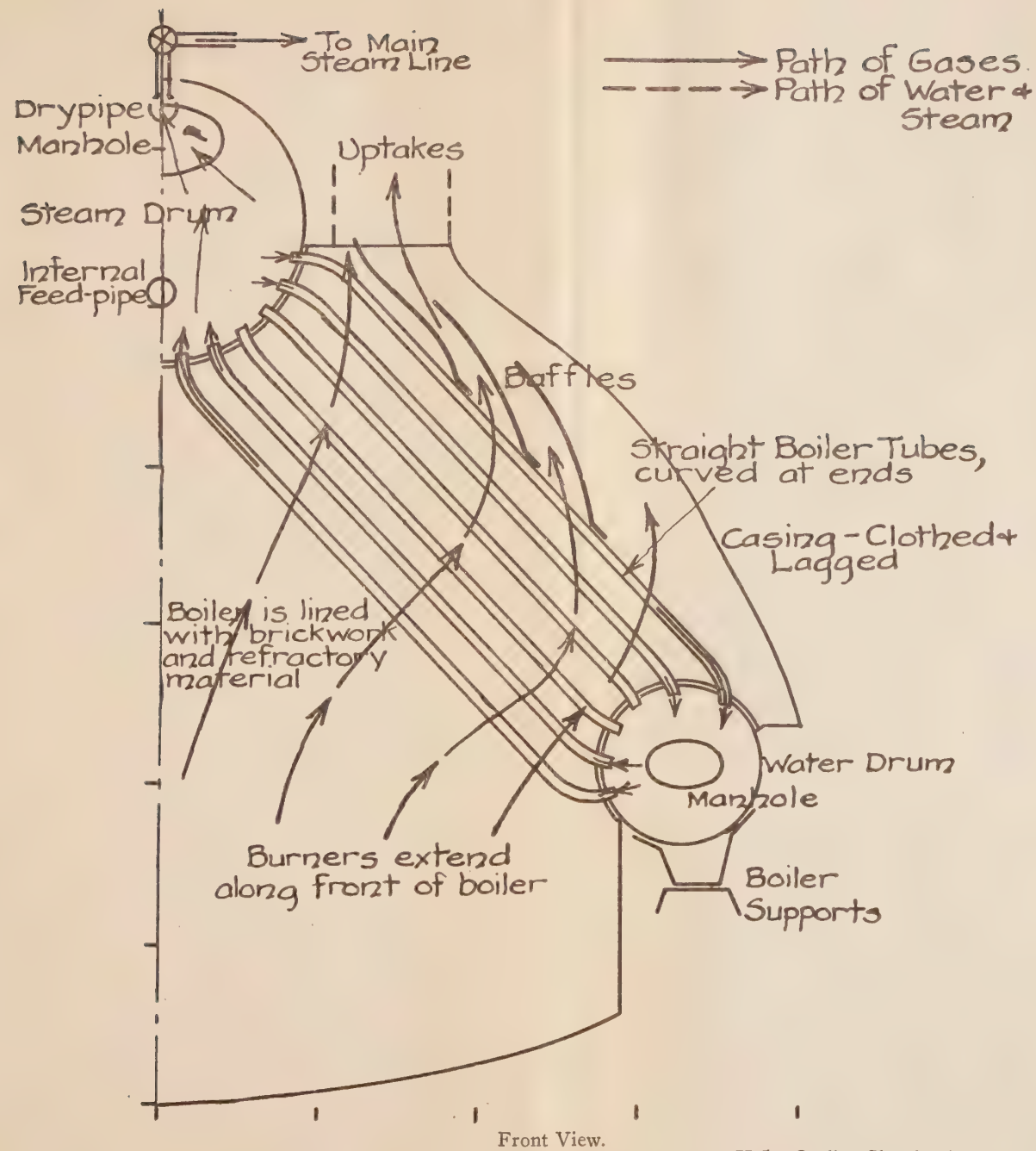
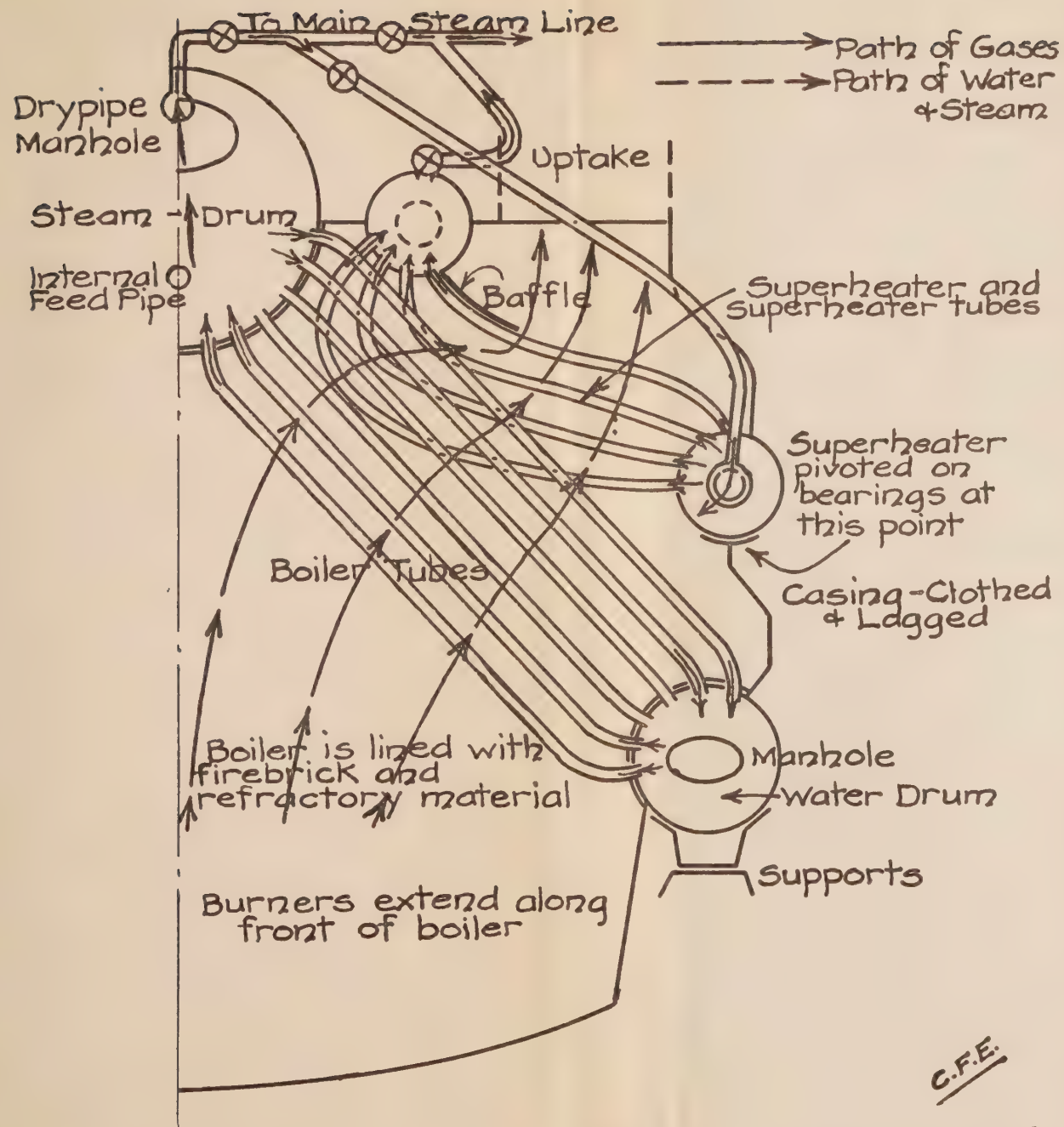
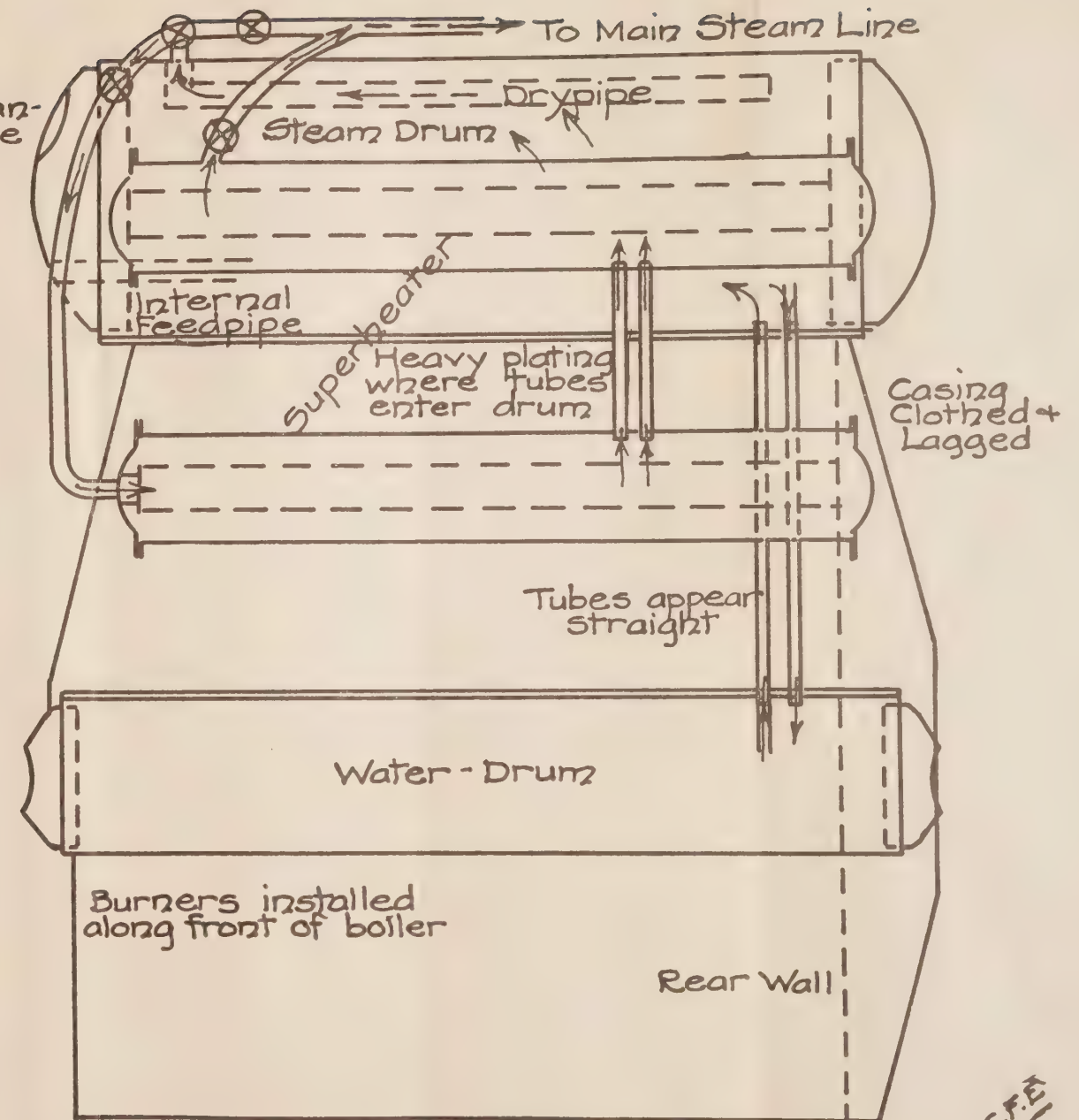


PLATE II-5.—Outline Sketch of Bureau Express Type Boiler (Dyson Design).

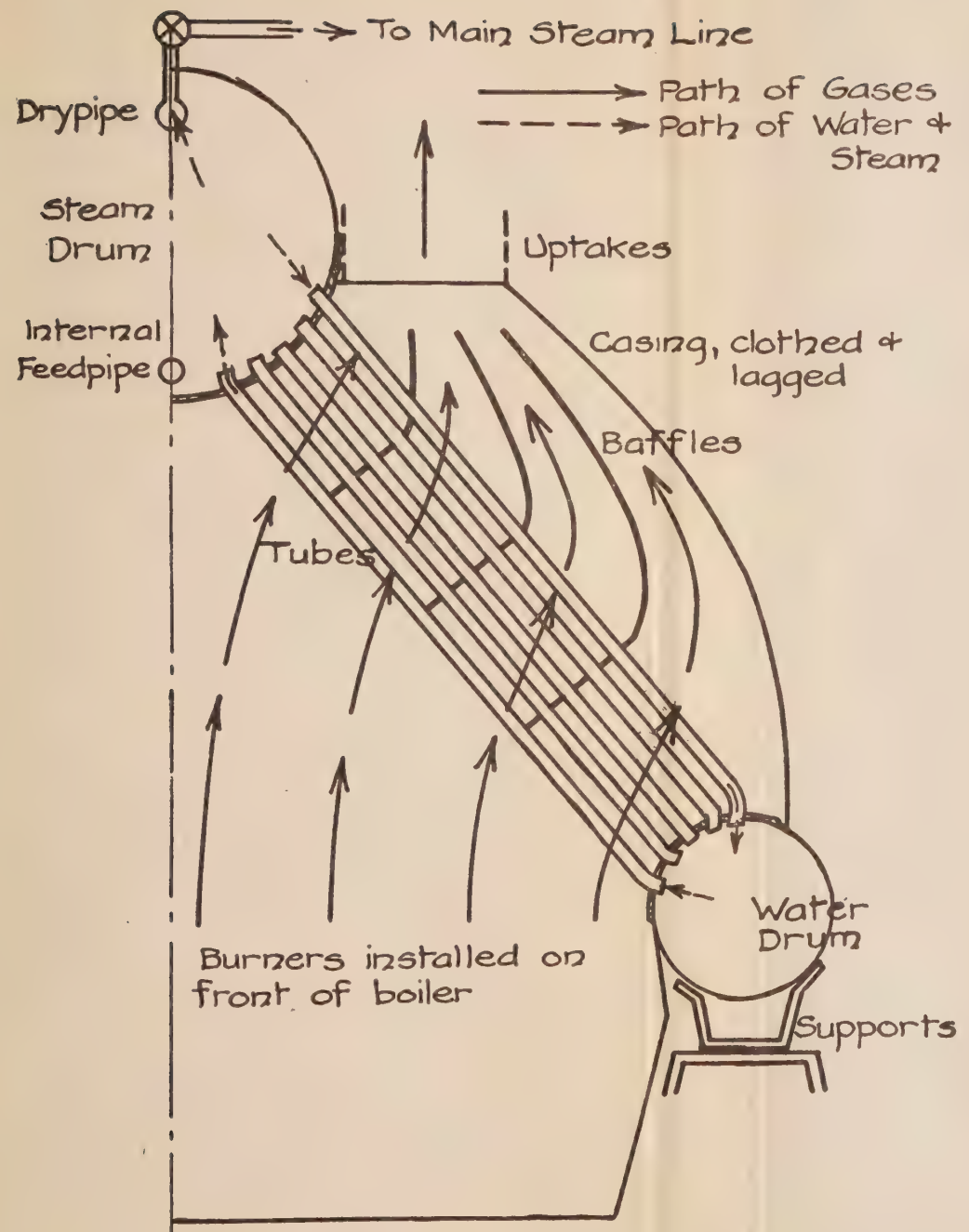


Front View.

PLATE II-6—Outline Sketch of Bureau Express Type Boiler (Dyson Design).

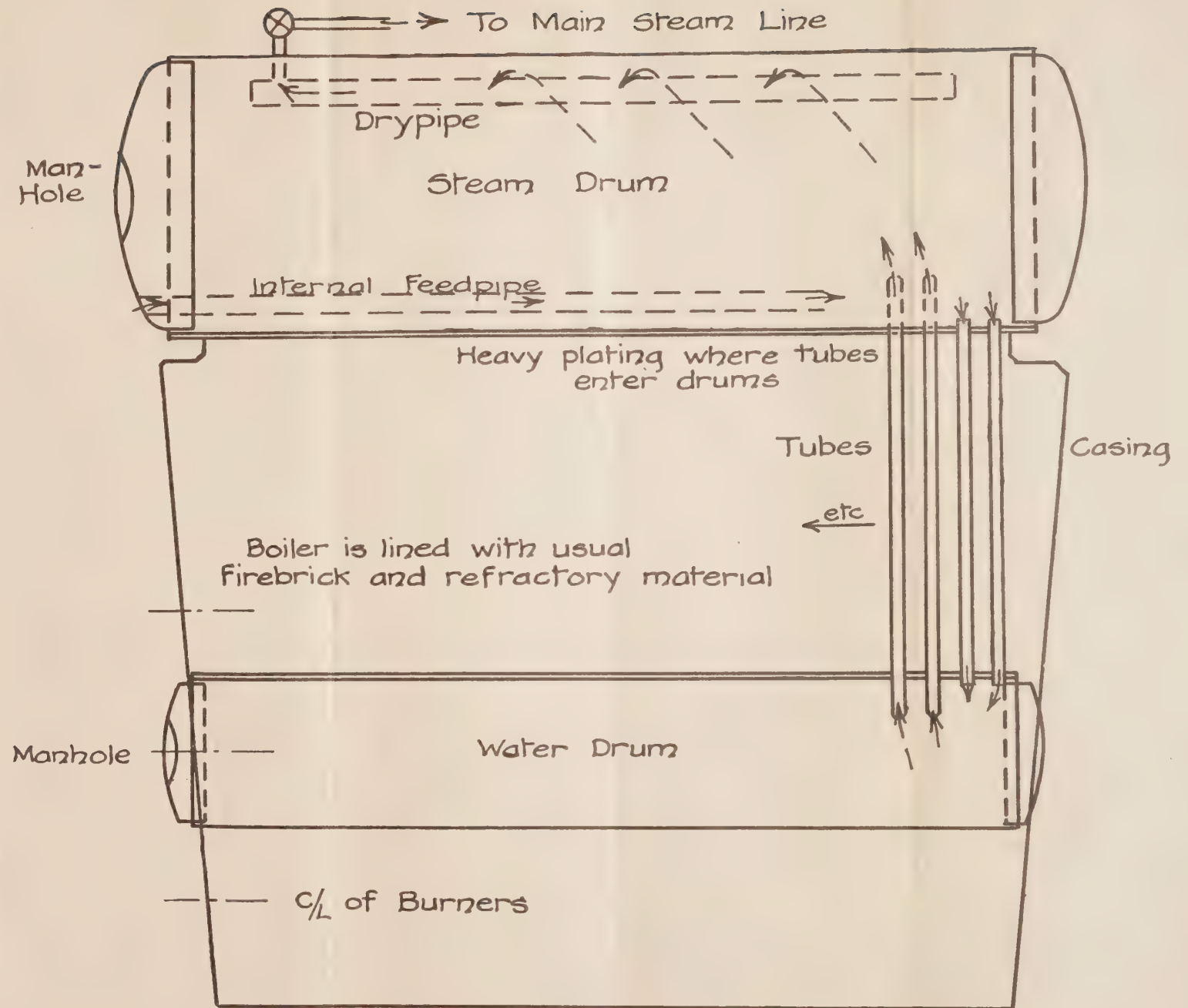


Side View.



Front View.

PLATE II-7.—Outline Sketch of Yarrow Boiler.



Side View.

The superheater consists of two small drums, connected by curved tubes, on each side of the boiler. The inner rows of superheater tubes are deeply curved and fit between the rows of generating tubes so as to provide gas baffling and so as to have the superheating surfaces near the furnace space. The superheater drums rest on steel supports built up from the saddles which support the boiler proper. The supports for the upper superheater drum can be removed and the saddle support under the lower superheater drum is designed so as to permit the rotation of the drums. When the fire sides of superheater and generating tubes are to be cleaned, the casing is removed, steam connections to superheaters are removed, supports for the upper superheater drums are removed, and chain falls are connected to the upper superheater drums. Then the whole superheater is revolved about the center of the lower superheater drum and swung out clear of the boiler proper.

The upper and lower superheater drums are fitted with dry pipes similar to the dry pipe in the steam drum. Steam, leaving the dry pipe of the main steam drum, goes from the boiler stop valve through a pipe to the dry pipe in the lower superheater drum, then up through the superheater tubes to the upper superheater drum, into the dry pipe in this drum and then through another steam pipe back to the main steam line. By-passes and cut-out valves are fitted so that either or both superheaters of a boiler may be cut out in an emergency in case of a leaky superheater.

Yarrow boiler.—The Yarrow boiler has the usual inverted V-shape, with no downcomers. It differs from other express-type boilers in the following respects:

- 1) The two rows of tubes (nearest the flame) are one and one-half inches in diameter; the other rows are one inch in diameter.
- 2) All tubes are straight in the main. The inner rows are bent slightly at both ends and the outer rows are bent slightly at the lower ends, to make the tubes enter the drums as nearly as practical on radii.
- 3) Three curved baffle plates are fitted on each side to direct and retard the gases of combustion.

Plate II-7 shows the Yarrow boiler. The circulation of the water and steam and the path of the gases of combustion are indicated by arrows.

2. FIRE-TUBE BOILERS

Fire-tube boilers are not now being installed in any of the armed vessels of the U. S. Navy. However, fire-tube boilers are found in a number of the auxiliary vessels now in commission. They are used on many ships in the merchant service.

Double-ended return boilers.—Plate II-8 shows two views of a double-ended return fire-tube boiler. Fig. 1 is a front elevation and Fig. 2 a side elevation with the right half in section through the center of the lower right furnace. The boiler is cylindrical, as may be seen from this plate.

The cylinder, closed at each end by a flat head, is called the *shell*. Built inside of the shell at each end are four furnaces *F*, each furnace having its own combustion chamber *A*, and nest of tubes *T*. The fuel is placed through the furnace doors *Q* on grates *G*, the gases of combustion pass from *F* into *A*, through *T* out of the boiler into front connection *C*; through the uptake *U*, through breeching* (not shown), through smoke pipe (not shown) to the atmosphere.

When the boiler is ready for steaming, the shell is filled with fresh water to about three inches above the top of *A'*; the water then completely surrounds all parts of the boiler in contact with the fire or gases of combustion in *F*, *A* and *T*. The space left above the water, called the *steam space*, collects and contains the steam as it is formed when combustion is taking place in *F*. Near the top of this space, steam may be drawn for use through slots in the dry pipe *D*, which connects with the stop valve *H'*, through an opening cut in the boiler head. By means of *H'* the supply of steam for use can be regulated.

The two furnaces on the right of Plate II-8, Fig. 1, are shown with the furnace front *R*, furnace door *Q*, and ash-pit door *P* removed. Fuel is placed on the grate *G* through door *Q*; and the air necessary for combustion of its volatile combustible gases is admitted over the fire through small holes in *R* and *Q*; and that necessary for the combustion of its non-volatile matter, under the fire through semi-circular openings left by removing *P*. The air finds its way up through the fuel.

The grate *G* consists of a series of grate bars supported on bearer bars, and it divides the corrugated furnace proper into the furnace *F* and the ash pit *F'*. The lower part of *F'* is covered with an ash pan *F''*. *S* is a slicing door in *Q* for working the fire without opening the door. *B* is a fire-brick bridge wall built on an iron frame; it makes a back wall for the fire, and slightly reduces the outlet for the gases of combustion as they pass from *F* to *A*.

C and *U* are secured to the outside of the boiler, and are, therefore, not integral parts of it. Access to the interior of *C* and *U*, and to the front ends of the tubes *T*, is obtained through the connection doors *I'*, three of which are shown in place; the fourth one is removed from its hinges and shows the front ends of the tubes. *SD* are soot doors in the bottom of *C*,

* The breeching connects the uptakes of several boilers to the common smoke pipe.

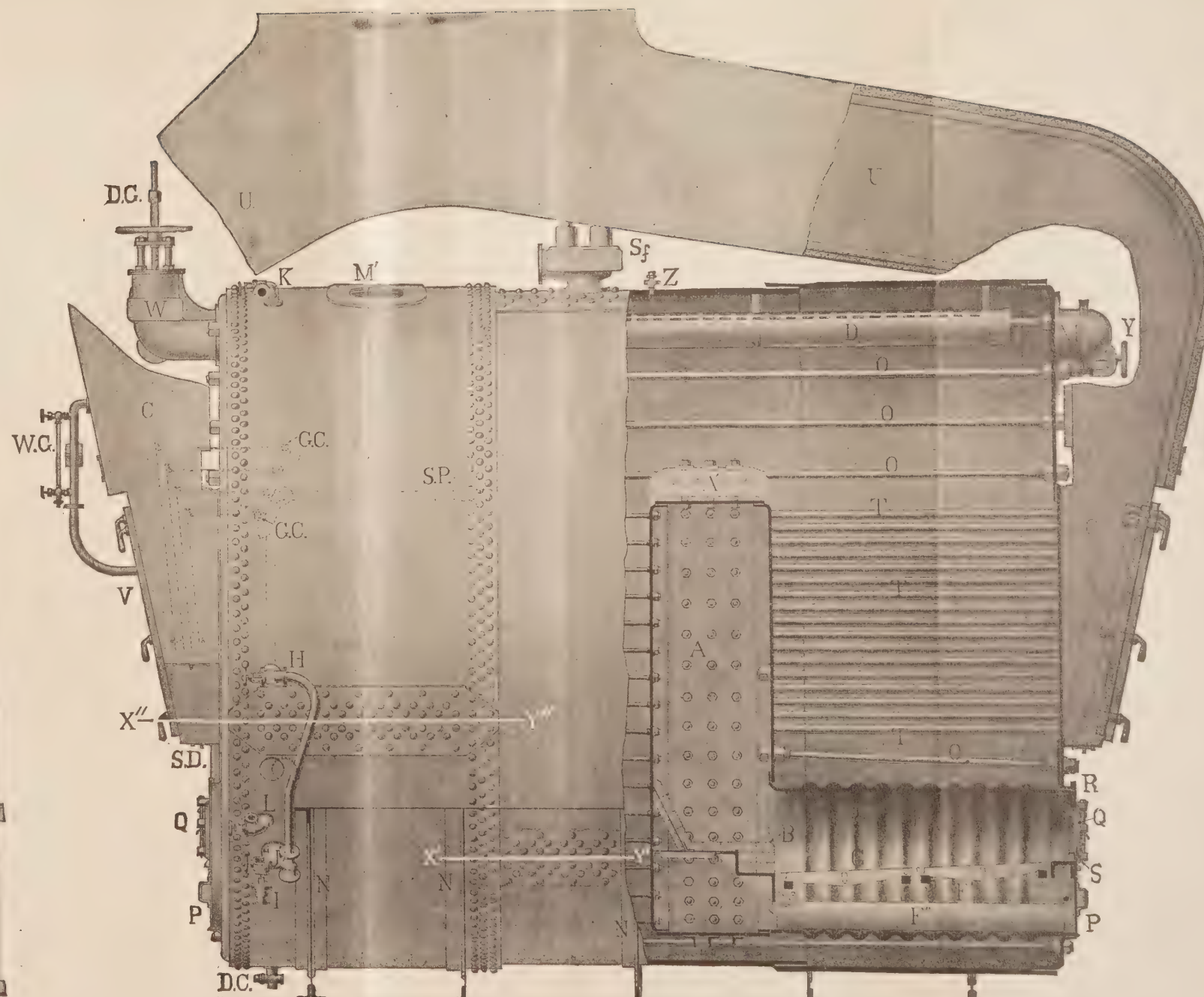
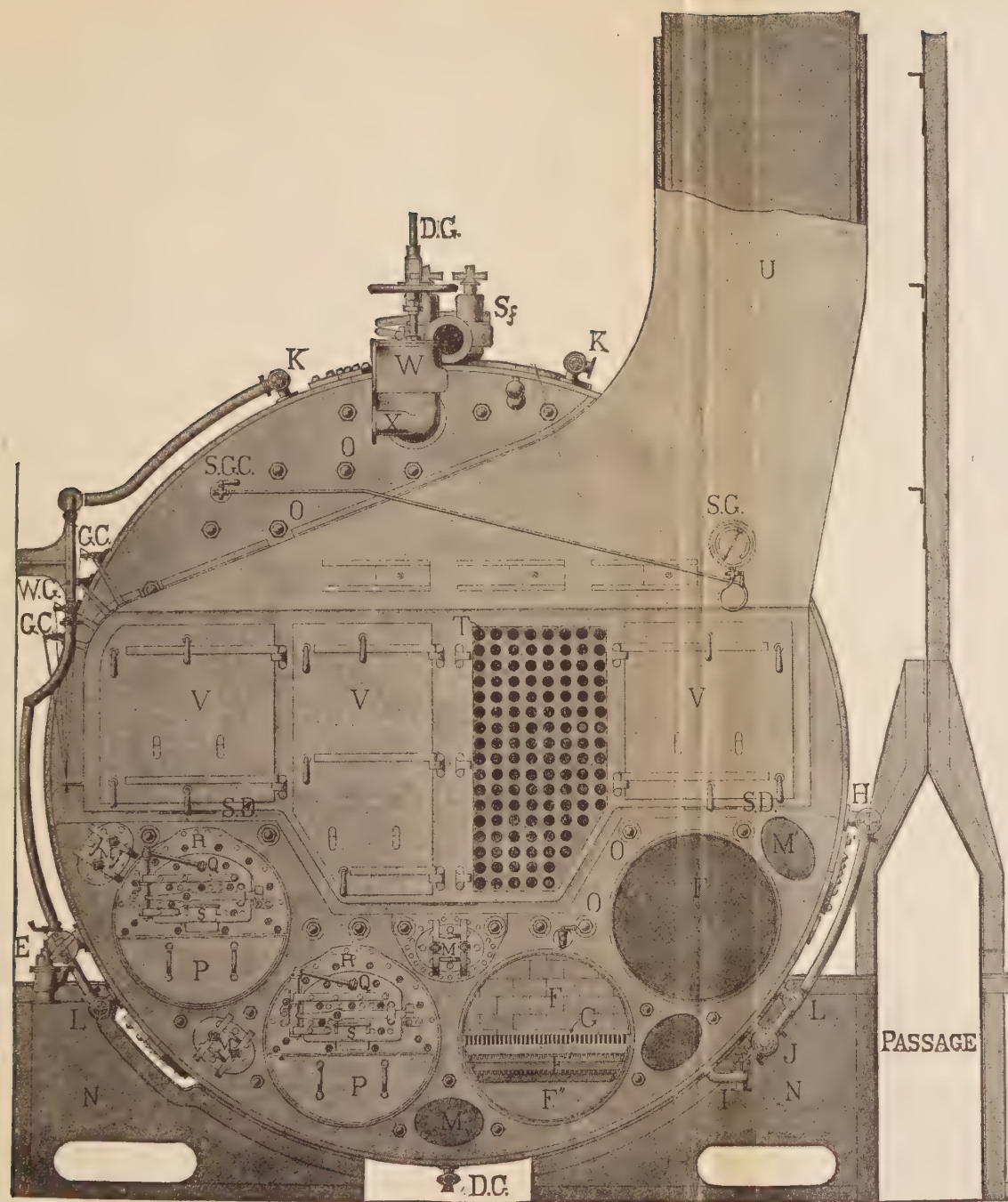


PLATE II-8.—Double-Ended Return Fire-Tube Boiler.

SCOTCH

and there are three sliding dampers above I' for regulating the draft and rate of combustion. The steam pressure, above the atmospheric pressure, inside the shell, is shown by the steam gage SG , and any excess of pressure above that at which the safety valves SV are set is relieved by them. The water-gage glasses WG and the gage cocks GC are used to indicate the water level in the shell. K and L are small valves on the water columns connecting WG to the steam and water spaces of the shell. The supply of water to the shell is regulated by means of the feed check valves and feed stop valve at E ; a pipe connects this with the feed pumps. Access to the interior of the shell is obtained through the manholes M' ; three of these are shown closed by the manhole plates M . H is the surface blow valve connected to the water in the shell by the internal pipe and scum pan SP . A pipe leading from H overboard is connected to the bottom blow valve J . I is the hydrokineter valve for aiding water circulation when getting up steam; there is one at each end of the boiler.

Z , at the top of the shell, is the air cock, and DC , at the bottom, is the drain cock. Y is the dynamo stop valve.

All flat surfaces exposed to pressure must be stayed, braced, or otherwise strengthened at regular intervals. The combustion chambers A are practically rectangular boxes of thinner plates than the boiler heads, and need much staying and stiffening. The flat heads are tied to each other by the braces O , of which there are four horizontal rows above the tubes and three surrounding the lower manholes. Similar braces, but shorter, tie the remaining flat and unbraced parts of the heads to the unbraced parts of the front combustion-chamber plates. The back and side plates of these chambers are stayed to those of the adjoining ones, or to the shell of the boiler, by screwed stay bolts; their flat bottoms are stiffened by three angle irons and their flat tops by the girders A' .

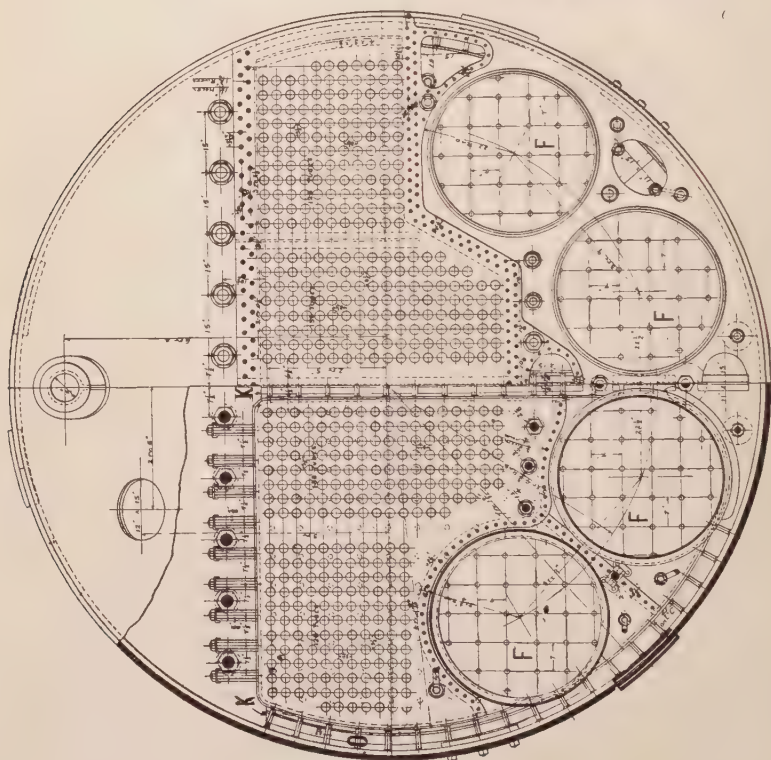
The front plate of the combustion chamber is called the *back tube sheet*; the middle plate of the boiler head is called the *front tube sheet*. These tube sheets are tied to each other by the ordinary tubes expanded into each plate, and by the heavier stay tubes screwed into each plate.

The boilers are supported by the saddles N built up from the hull of the ship, and are placed in water-tight compartments called *boiler compartments*.

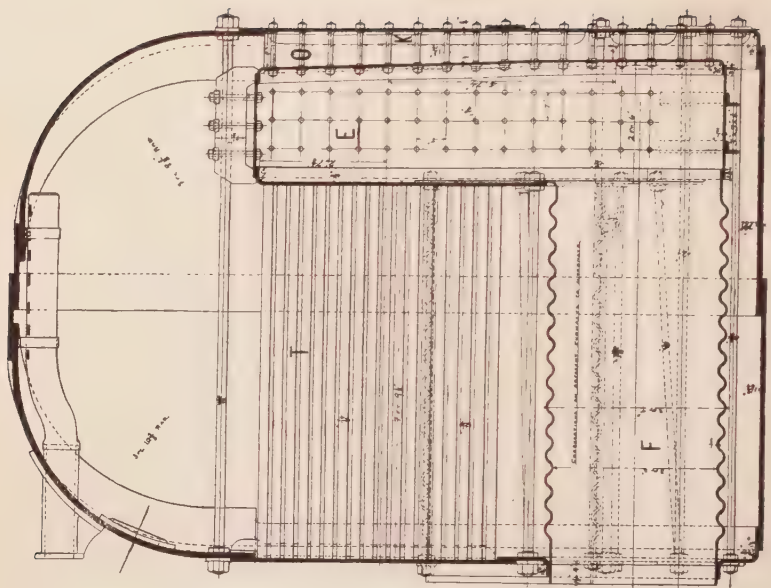
The saddles are generally secured to the shell by means of brackets which are riveted to the shell and bolted to the saddles.

The uptakes of a certain nest or number of boilers join in the breeching at top of which is set the smoke pipe.

The rectangular enclosing the outside limits of the grate is called the *grate surface*.



(a)



(b)

FIG. II-5.—Single-Ended Return Fire-Tube Boiler.

Single-ended return fire-tube boiler.—Fig. 41-5 shows two views of a single-ended return fire-tube boiler. The right half of (a) is a front elevation of the boiler, with the connections and uptake removed, and the left half of (a), a section through the middle of the length of the boiler. *FF* are the furnaces, *E* the combustion chamber, one for each furnace, and *T* the tubes. The heads, instead of being flat, as in the double-ended boiler, are bent back at the top. By this construction, the two upper rows of tubes become unnecessary, but the steam space is somewhat reduced. (b) is a longitudinal section through the center of the right lower furnace. The manner of staying the combustion chamber sides to each other and to the shell is shown by the screw stays *O*, *O*. The flat back head of the boiler between adjoining combustion chambers is stayed by T bars, shown in the sketch, but not lettered.

The front head between adjoining nests of tubes is similarly stayed. The single-ended boiler is heavier and more expensive than the double-ended one for the proportional heating surface, and its evaporative efficiency is, in practice, generally lower. The remaining parts are similar to those of the double-ended boiler already described.

3. TREND IN BOILER DESIGN

In order to show the trend and striking advance in marine boiler design herein advantage has been taken of shore plant experience see Figure II-6. This is a Foster "A"-type marine boiler, and although it has not as yet been installed on any naval vessels, it shows possibilities which may be later used in the U. S. Navy. Note its similarity to naval inverted "V"-type boilers. Digression will here be made from our regular subject to devote a brief explanation to the various features shown in this particular boiler:

Economizers.—Virtually feed-water heaters. Water from the main feed line passes through nests of tubes which are exposed to the hot gases from combustion escaping to the stack. The temperature of the feed water thus is raised from 212°-220° F. to 300°-340° F., and the stack gas temperatures correspondingly reduced. Raising feed water temperatures to 300°-340° F. precipitates impurities which lodge in the economizer tubes keeping the boiler tubes free of scale, and such feed water upon entering the boiler approximates flash evaporation.

Water walls.—To reduce furnace-wall temperature and radiation, water walls have been fitted to this boiler. These consist of a series of U-shaped tubes, fitting completely around the side walls and whose ends are connected to the lower drums as shown. Water circulating through the tubes absorbs radiant heat and is converted to steam.

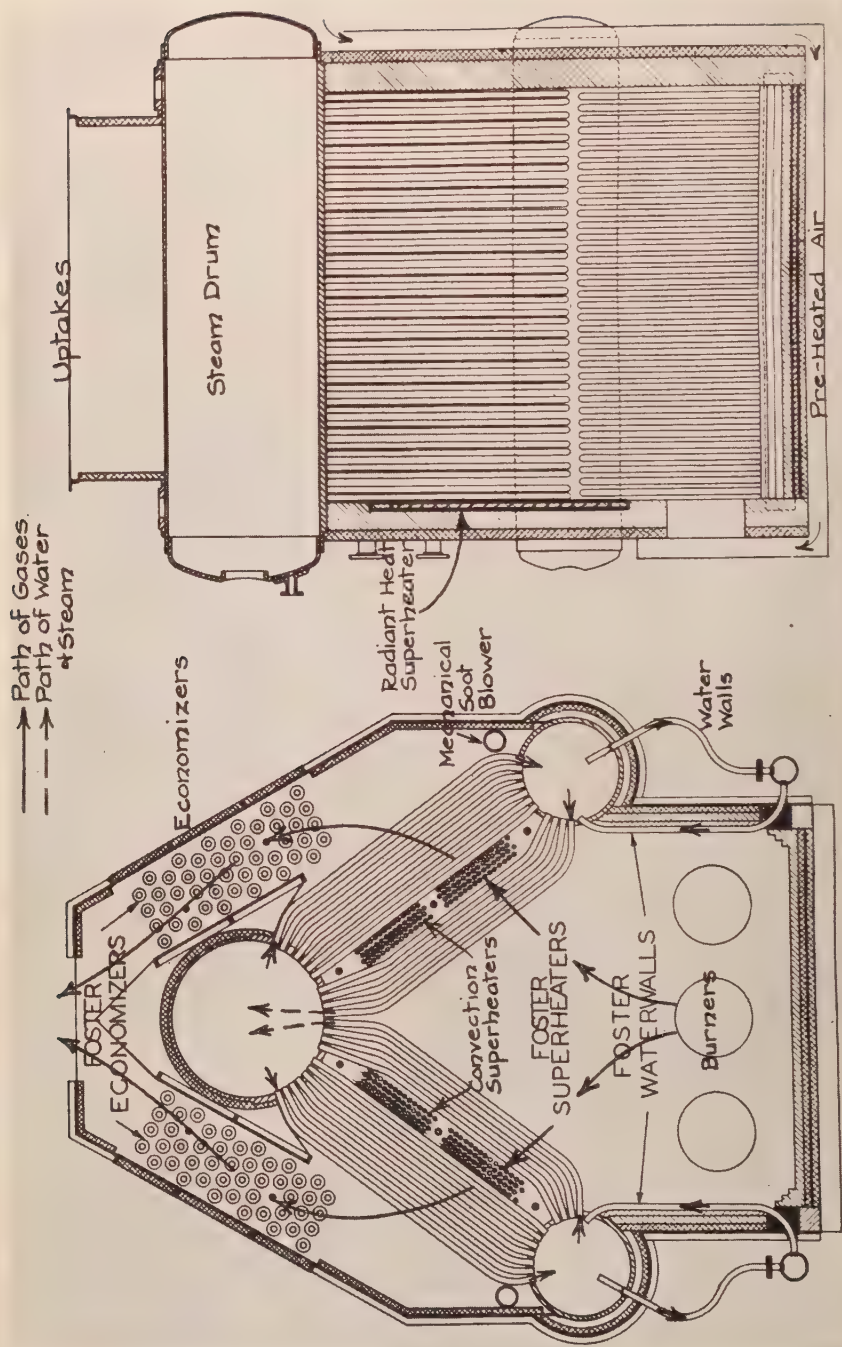


FIG. II-6.—New "A" type Foster marine steam generator consisting of "A" type boiler,

Air preheater.—If the great quantity of air necessary for the proper combustion of fuel oil can be heated prior to entry into the boiler greater efficiency will result, for the boiler would not be partially chilled as in the use of cold air. Some boilers accomplish this by use of a special air preheater which consists of a series of hollow plates and air paths located in the uptakes. Air from the atmosphere is forced through the heater, which is kept hot by the passage of the gases of combustion. Air thus heated is then fed through the registers for combustion of the oil. In this particular Foster boiler the same object is obtained by suction of the air down between the boiler casing and rear wall, thence under the boiler itself, thence up between the casing and front wall, and finally forced into the boiler. The hot walls heat the air and the air helps to keep these walls relatively cool.

Radiant heat superheater. The purpose and operation of this superheater is identical with the common convection type superheater of which we have already studied. The difference lies in the fact that this superheater is located on the inboard side of the front wall and consists of rows of flat vertical tubes. Another difference is that this type superheater is heated by and absorbs radiant heat, by means of which a higher degree of superheat can be obtained. It also serves as a furnace wall cooler and insulator.

Convection superheater.—This is about the same general type as the standard U-tube with which we are already familiar. An improvement in construction, however, is the fact that this superheater is built of a special heat resisting alloy steel and its U-tubes are fitted with cast iron fins. These not only increase the heat absorbing area but also protect the tubes from corrosion.

Mechanical soot blowers.—One blower consists simply of a long hollow pipe, fitting horizontally behind the tubes as shown. About one-half its surface is perforated similar to the dry pipe of a boiler. The blower is connected to a wheel and hand chain on the outside of the boiler and is capable of complete rotation and a slight movement fore and aft. High-pressure steam is used to blow with; and with proper attention, tubes can be kept almost entirely free of soot.

CHAPTER III

BOILER FITTINGS

The fittings on a marine boiler are:

- S (1) *One steam stop valve*, closing toward the boiler, arranged for distant operation from the deck or adjacent compartment, for regulating the flow of steam to the main steam pipe or line or for closing the steam off from the boiler to the steam line.
- (2) *One auxiliary steam stop valve*, when required. Same as (1) except that it connects with auxiliary steam pipe.
- (3) *One dry pipe in steam drum* (in shell for fire-tube boilers), for preventing foam or water from being carried into the steam pipes.
- W (4) *Two combined feed stop-and-check valves* (one main and one auxiliary), connecting to an internal feed pipe, for controlling the amount of feed water admitted to the boiler and for shutting off either main or auxiliary feed line as desired.
- W (5) *Internal feed pipe or pipes*, connecting to feed stop-and-check valves, for distributing the feed water through the entire length of the steam drum.
- W (6) *One surface blow valve*, high-pressure globe types, with internal pipe and scum collector, for removing grease or scum from the surface of the water in the steam drum or shell.
- W (7) *One or more bottom blow valves*, of the seatless type, with internal pipe or pipes, for removing dirty water, sediment, or loose scale from the bottom of the water space. The bottom blow valves are also used for "blowing down" to reduce the saturation when it gets too high, and for pumping the water out of the boiler.
- S (8) *Two or more safety valves* (usually twin or triple valves), set to lift at the authorized pressure and to blow the excess steam off through an escape pipe to the atmosphere. Where the superheater is fitted with a by-pass, a separate safety valve is installed on the superheater to protect it.
- S (9) *One steam gage* to register the pressure of the steam in the boiler.
- W (10) *Three gage cocks*, operated from the fireroom floor, to show the approximate water level.
- W (11) *Two water gages* with automatic fittings, to show the level of the water in the boiler.

Fuel Burner = 1

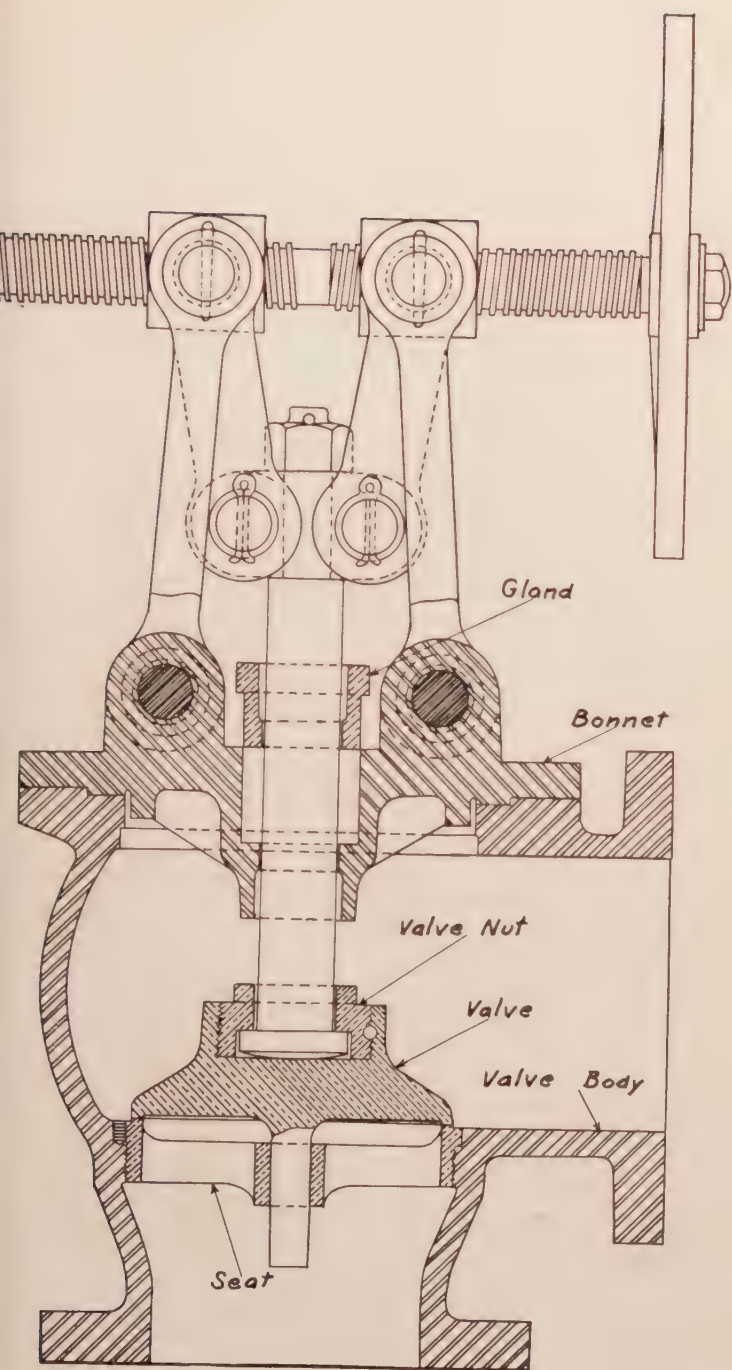


FIG. III-1.—Boiler Stop Valve.

- W (12) *One air cock*, a small, high-pressure globe valve, at the highest part of the steam space, to let the air out of the boiler as it is pumped up or as steam forms in it and to let air in the boiler as the boiler is emptied.
- W (13) *One or more drain cocks or valves*, of high-pressure globe type placed at the lowest part of the water space, to draw all of the water out of the boiler.
- W (14) *One or more connections for drawing water for test.*
- F (15) *Soot blowers for boiler and superheater tubes.*
- F (16) *A connection for flue gas-analysis outfit.*
- F (17) *A permanent connection for taking the air pressure in the furnace.*
- S (18) *A connection for a steam calorimeter.* *See instrument in steam*

Boiler stop valve.—Figure III-1 is a cross section of a boiler stop valve. The valve body and bonnet are of cast steel. The valve is flat seated and made of monel metal. The stem is of forged steel. The valve seat is removable and is made of monel metal. The valve stem is moved up and down to open and close the valve by a system of links and traveling nuts operated by the hand wheel. The valve can be opened from a station outside the fireroom by a system of rods, universal joints, and gears, which are not shown in the figure. The operating gears and distant control gears differ in different ships. This type of valve is also used for bulkhead stop valves and cut-out valves. By-passes are fitted on large valves of this type to equalize the pressure on both sides of the valve before opening.

Figure III-2 shows an ordinary stop valve, made by Jenkins Brothers. The surface blow valve, air cock, drain cock, and water test valve are of this type. The valve consists of the following parts: —————→

Feed-stop-and-check valves.—Each boiler is fed through two combined stop-and-check valves called the *main* and *auxiliary* feed stop-and-check valves. The main feed stop-and-check valve connects the internal feed pipe with the main feed pipe and the auxiliary feed stop-and-check valve connects the internal feed pipe with the auxiliary feed pipe. The two valves and two feed systems are provided for safety in case one of the feed systems fails to work.

Figure III-3 shows a combined feed stop-and-check valve. Between the check valve *K* and the drum *O* there is the stop valve *G*, by means of which the check valve and feed pipe can be isolated from the boiler to permit the overhaul of the check valve when steam is on the boiler.

The valves are in the composition chamber *H* which connects with the feed pipe at *Q* and has an outlet through the nozzle *L* to the internal feed pipe *F*. The check valve *K* is held on its seat by the spring *P* and is guided

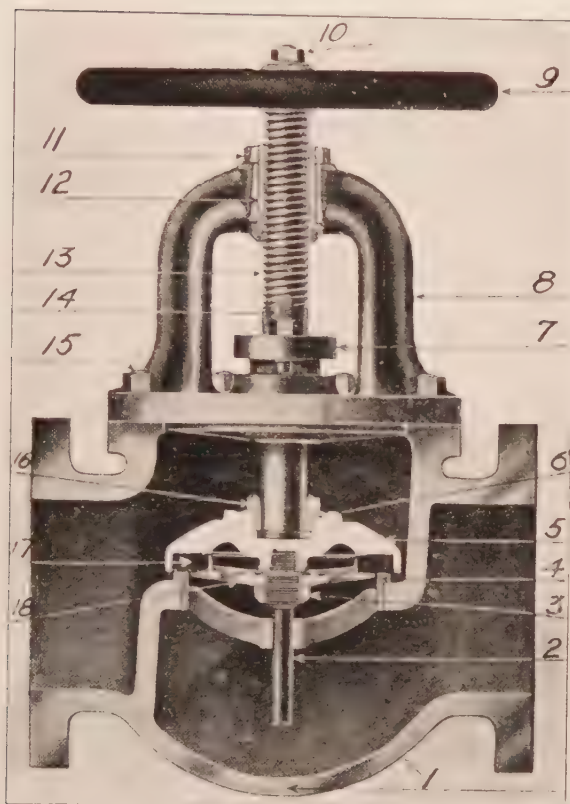


FIG. III-2.—Ordinary Stop Valve

Body—cast steel.

Guide stem—composition.

Disc nut—composition.

Seat ring—monel metal.

Disc holder—composition.

Cotter pin—brass.

Gland—composition.

Yoke—cast steel.

Wheel—composition.

(10) *Wheel nut*—composition.

(11) *Jam nut*—composition.

(12) *Yoke nut*—composition.

(13) *Valve stem*—rolled steel.

(14) *Gland stud bolt*—composition.

(15) *Yoke stud bolt*—rolled steel or composition.

(16) *Lock nut*—composition.

(17) *Disc*—monel metal.

(18) *Disc plate*—composition.

In small-sized valves, parts 3, 17, and 18 are frequently combined as one piece, made of monel metal.

in its up and down motion by the spindle which fits into a guide in the valve body below the valve seat and by the socket into which the lower end of the valve stem *C* fits. The amount of movement or opening of the check valve is regulated by the collar *D* on the valve stem *C*. The valve stem *C* is threaded at its upper end to fit the threads in the yoke *B*, so that a turn of the handle *A* causes the valve stem *C* to move up or down.

When the valve is in operation the stop valve *G* is kept open and boiler pressure on the back of the valve *K* keeps the check valve shut. When the

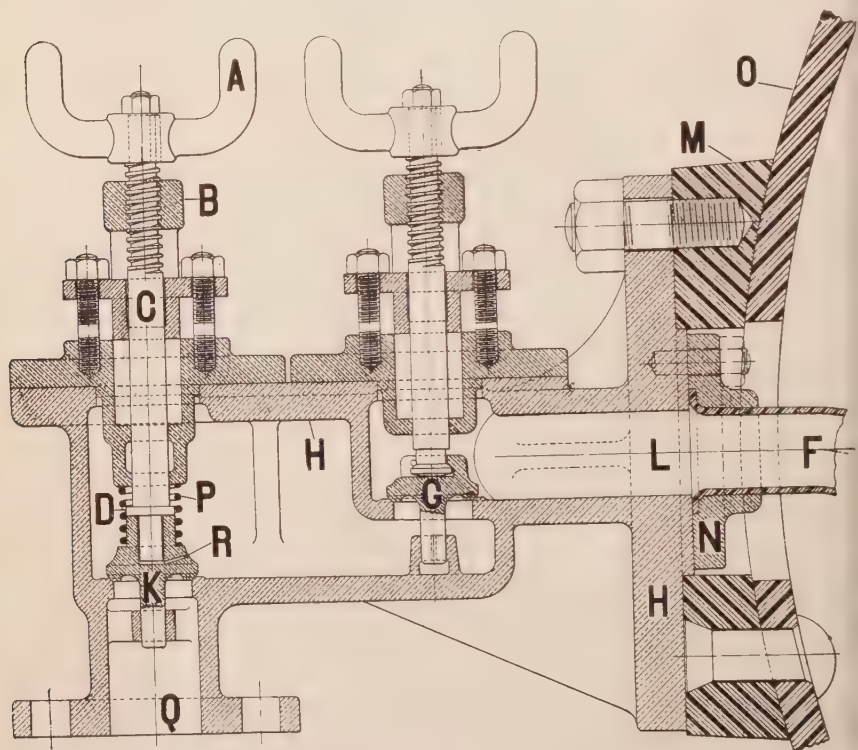


FIG. III-3.—Combined Feed Stop and Check Valves.

boiler is to be filled, the handle *A* is turned slightly, raising the collar *D* a certain distance. The valve can now lift that distance whenever the pressure below it in the feed pipe is greater than the boiler pressure on the back of the valve. When the feed pressure drops, the boiler pressure and spring pressure on the back of the valve force the valve down on its seat. When a reciprocating feed pump is used the valve will alternately open and close with each stroke of the pump, with an audible click. There is no such rapid fluctuation of feed pressure with a rotary feed pump, so the

check valve remains open. The smaller holes *R* are drilled through the valve to the bottom of the guide socket on *K* for the escape of water as the valve lifts. The check valve seat is always lower than the internal feed pipe so that a water seal is maintained.

The check valves are operated from a grating or from the fireroom floor plates by means of reach rods and spur gears which turn the valve stems.

Internal feed pipes.—The feed water is distributed from the main and auxiliary feed stop and check valves over the length of the steam drum by one or two internal feed pipes. Each feed stop and check valve may have its own internal feed pipe or both may be connected to the same internal feed pipe. The internal feed pipe is located on or near the vertical center line of the steam drum with the top of the pipe approximately one-fourth of the steam drum diameter above the bottom of the drum. Discharge holes $\frac{3}{8}$ inch or more in diameter are drilled along the upper side of the pipe so as to spray the feed water upward. The aggregate area of the holes is twice the cross-section area of the pipe.

Dry pipe.—The dry pipe is a thin steel pipe, extending nearly the length of the steam drum (or shell for fire-tube boilers), and perforated on its upper side with slits or holes. The combined area of the slits or holes must not be less than one and one half times the cross-sectional area of the steam pipe leading from the boiler. The dry pipe is fitted as near the top of the steam space as possible. One end of the dry pipe is secured to the stop valve nozzle and the other end is closed. Steam, in going from the boiler to the steam pipe, must rise to the top of the steam space and then pass down through the holes or slits in the top of the dry pipe. This change in direction of the steam prevents "priming" by making the water particles, which may be carried in suspension, drop out of the steam. The long dry pipe has the additional effect of making the evaporation uniform. One or more small drain holes in the under side of the dry pipe prevent the accumulation of water. The safety valves are usually connected to the dry pipe. See Fig. III-4.

Surface blow valves.—Extra heavy ordinary screw down globe valves are used for surface blow valves. They are installed so as to close against the boiler pressure. The surface blow valve is connected to an internal blow pipe which runs the entire length of the steam drum about two inches below the normal water level and has slots on the upper side along the entire length. In some boilers a shallow pan called a scum pan is fitted just below the internal blow pipe. Grease, foam, or any other floating impurity may be blown out through the surface blow valves. See Fig. III-4.

Bottom blow valves.—One or more bottom blow valves are fitted

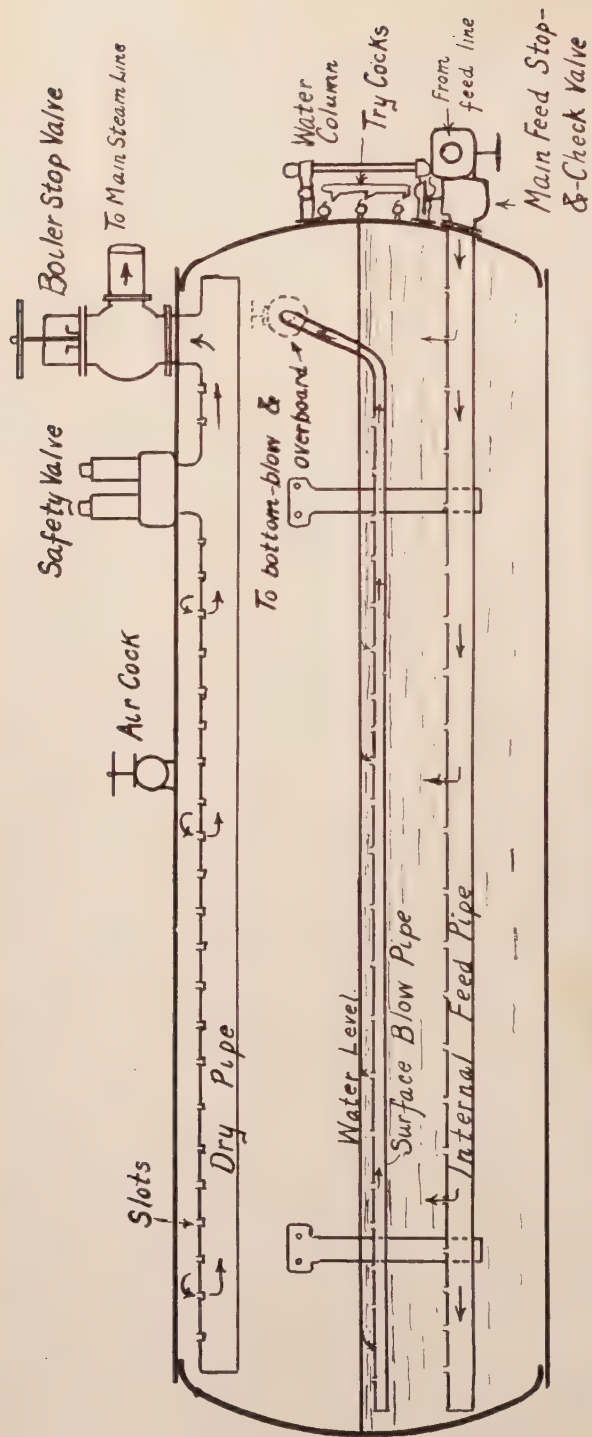


FIG. III-4.—The location of the various fittings attached to the steam drum of a boiler is shown in Figures III-4 and III-5.



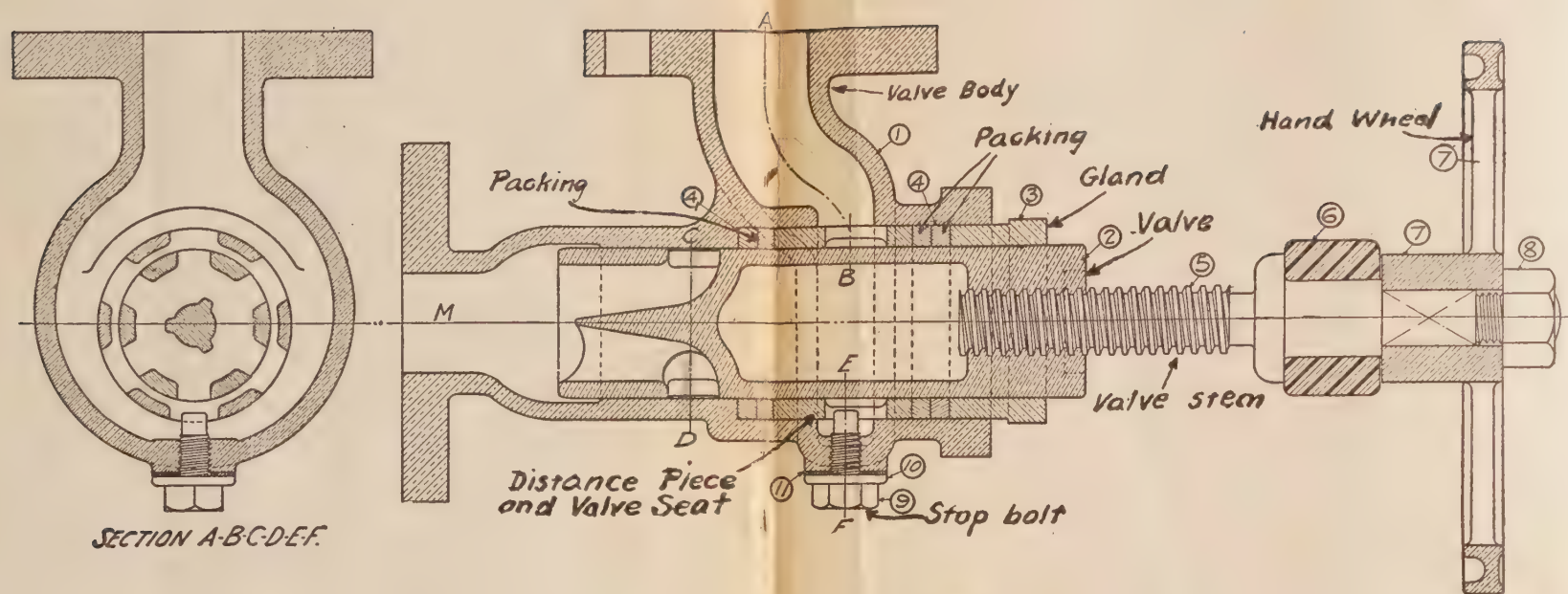


PLATE III-1.—"Seatless" Bottom Blow Valve. In closed position.

the lowest part of the water space in each boiler. The surface blow and bottom blow valves of each boiler are connected by a pipe with a short direct lead to a sea valve in the ship's bottom under the boiler room. The standard type of bottom blow valve is shown in Plate III-1. It is of the "seatless," hollow piston type, and has no projection upon which sediment and scale can accumulate. The pressure is against the side of the piston

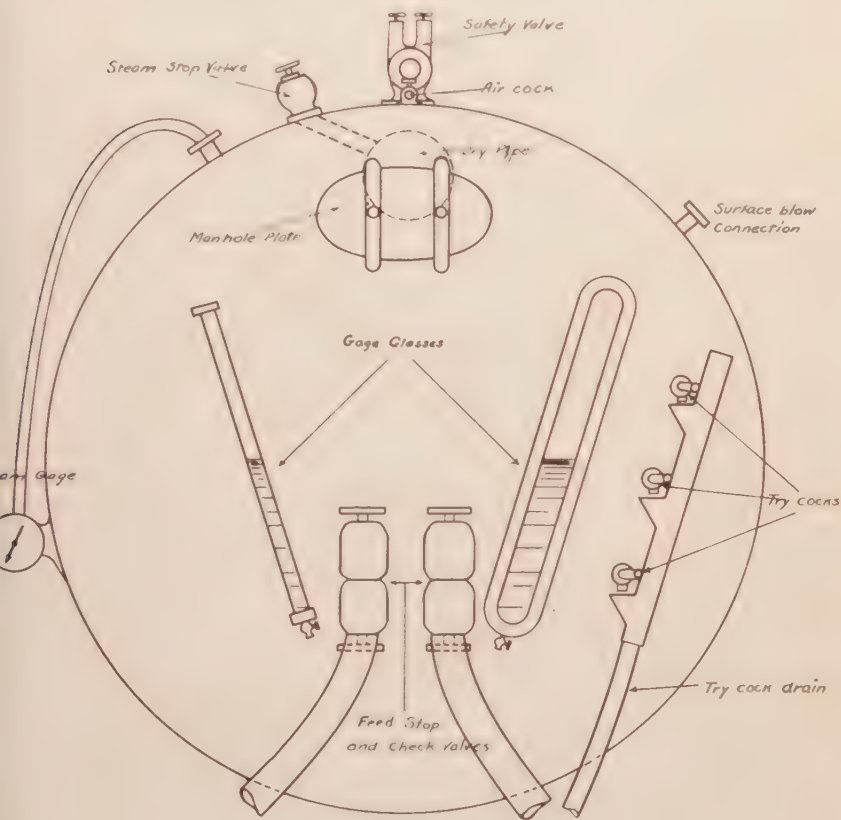


FIG. III-5.—Steam Drum—Front View.

When closed. The valve is opened by turning hand wheel 7, thus moving the piston so that an opening *CD* in the piston wall is in line with the opening *BE* in the valve body. Packing (4) around the piston keeps the valve tight. The gland (3) sets up on the packing at (4). The two sets of packing are separated by the distance piece which has openings in line with *BE*, the openings in the valve body. The gland studs are not shown. The stop bolt holds the distance piece in such a position as to make the

holes in the distance piece line up practically, with the opening *BE* in the valve body.

The bottom blow valves are used:

- (1) *To reduce the salt concentration* by blowing some of the water out of the boiler. The more concentrated brine will be heavy and will be at the bottom of the water space near the bottom blow valves.
- (2) *To remove mud and sediment* from dirty boiler water by blowing down as in (1).
- (3) *To empty a boiler* by means of a pump. A section of hose or portable pipe may be connected to the blow pipe line and an auxiliary

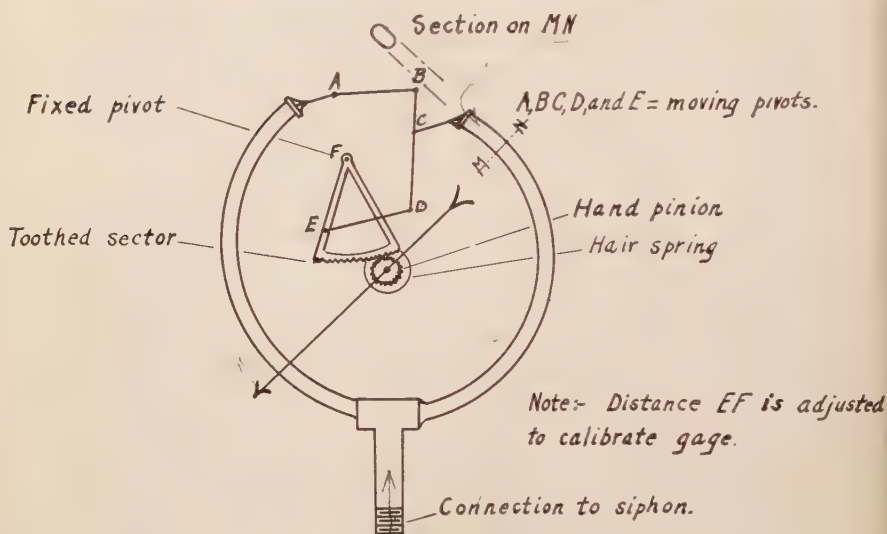


FIG. III-6.—Double Spring Pressure Gage. Ashcroft Mfg. Co. Type.

feed pump may be used to pump the water out of a boiler and discharge it overboard or to a reserve feed tank or another boiler. In this way boiler water, which is too dirty or salty for feed purposes may be used to wash out another boiler.

Steam gages.—Each boiler is fitted with one or more steam gages to measure the steam pressure to pounds per square inch. Figure III-6 is a diagram of a type of steam gage which is in general use. The gage is connected to the boiler by a gage connection pipe which is bent in a coil of one or two turns to form a siphon. The siphon is made sufficiently large to contain enough water to fill both springs when under pressure, and so fitted that this water seal will not be drawn out of the siphon when the pressure is off. This arrangement prevents the ill effect of actual contact of the

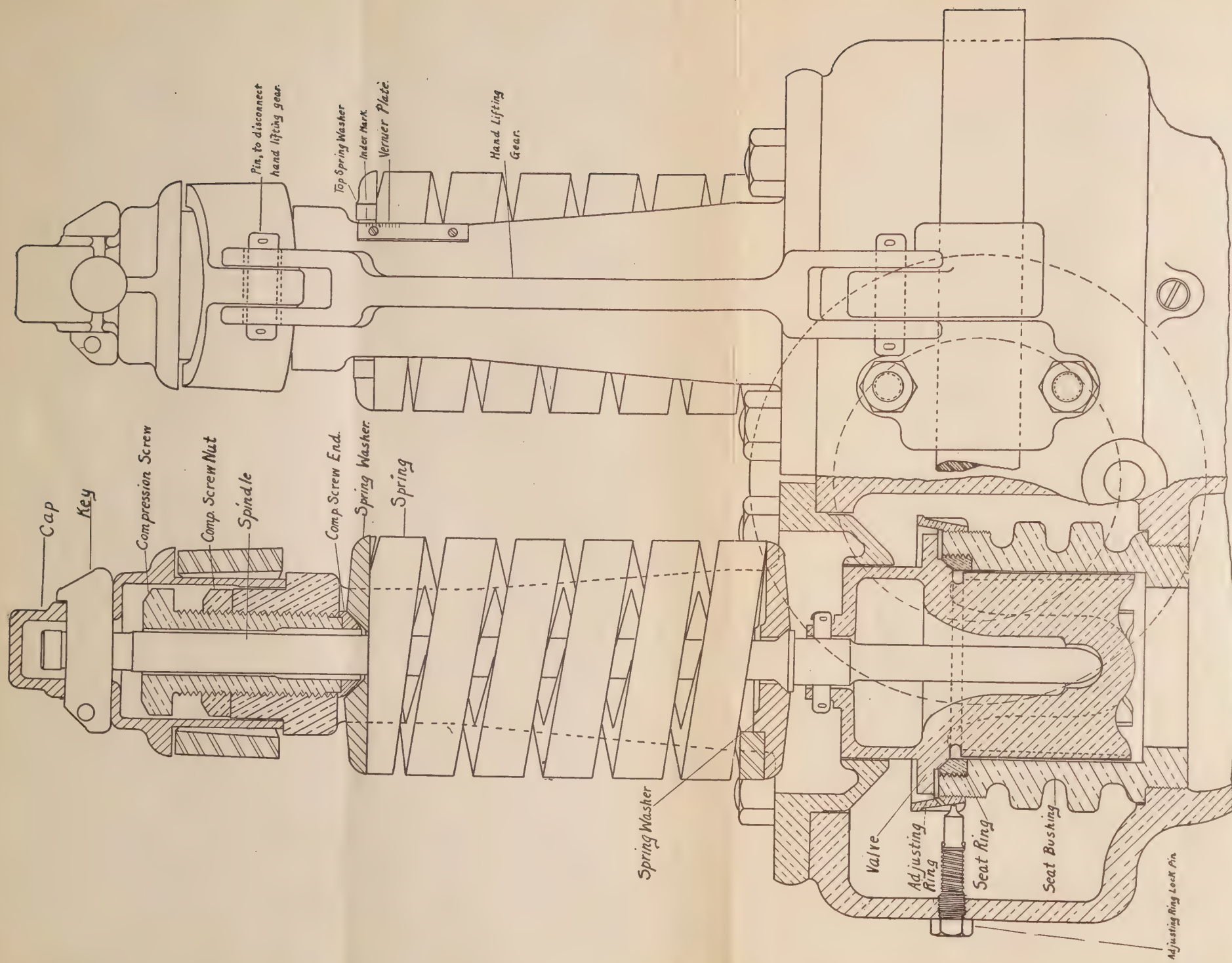


PLATE III-2.—4 inch Duplex Safety Valve. U.S.S. Saratoga.

eam with the springs. A small cock, by which the gage can be shut off, fitted between the siphon and the gage.

The springs being elliptical, with the longer diameter perpendicular to the curvature of the spring, any increase of pressure on the inside will tend to equalize the diameter of the ellipse, and thus cause each tube to straighten, that is, to move the closed ends away from each other. The diameters of the ellipse will tend to equalize because any pressure inside the tube tends to make the tube take its greatest cross-sectional area, which for a given length of periphery is the circle. This can be understood by folding a strip of paper on itself several times, closing one end and rolling on the folded paper. Blowing into the open end will straighten out the roll. This general type of spring is called the Bourdon type. The elasticity of the metal of the springs, if not exceeded, will bring the ends back to their normal position when the pressure is decreased. The hair spring keeps the joints of the mechanism pulled in one direction, preventing lost motion. A small pin on the dial stops the pointer at a little above zero.

The dial is graduated for every five pounds by comparison with a mercurial column. To make sure that the boiler gages give reliable indications, they must be tested at least quarterly on naval vessels by comparison with a standard test gage or a gage testing apparatus.

Safety valves.—Safety valves are fitted to prevent the pressure in the boiler from rising above the safe working limit and to provide a ready and automatic means of escape for the surplus steam. This is accomplished by opposing the resistance of a spring, acting on one side of a valve, to the steam pressure in the boiler acting on the other side, the chambers to which this valve opens being connected to the atmosphere by the escape pipe.

Plate III-2 shows an example of a duplex pop safety valve of the Navy pattern. The type shown here is called the "Duplex," on account of two valves being enclosed in one casing. They are also made in the single, triple, and quadruple types. The valves are the same for all types of the same make. Two or more valves are usually fitted instead of having the necessary area put into one valve. Safety valves are placed vertically whenever possible. When safety valves are placed horizontally, they are very hard to keep tight because of the play between the wings of the valve and the seat.

The lower part of the casing is connected to the dry pipe of the boiler and the upper part to the escape pipe at the flange indicated by the two dotted circles.

The safety valve spring is of the highest quality steel, nickel plated, and square in section. Each spring is made long enough to allow the valve to

lift *one-eighth* of its diameter when the valve has been set at the designed working pressure.

To overcome the effect of any tilting of the spring when the valve opens and consequent binding of the wings of the valve against the sides of the seat, the valve spindle bears against the valve with a spherical bearing at a point near the bottom of the valve and the valve has very long guide wings. The connection between the bottom spring washer and the valve spindle is also a spherical bearing.

The composition seat bushing screws into the casing and serves as a guide for the valve and holds the monel metal seat ring. The top of the seat ring is carefully machined and ground to a cone seat for the valve.

The valve is held on this cone seat by the pressure of the spring transmitted by the valve spindle. Above the seat the valve is enlarged in diameter to form a projecting lip. At the top of the valve, it is loosely connected to the spindle by a key. This arrangement permits the valve to be lifted from its seat by the hand lifting gear.

The adjusting ring is screwed on to the outside of the seat bushing. At the left of the adjusting ring in the figure is a ring locking pin with a spring and locking tip, which locks the adjusting ring in position. The spring prevents damage to the adjusting ring by the pin.

Suppose the valve to be an ordinary valve with a conical face just covering the seat. The spring, being under compression to resist a certain pressure, would allow the valve to rise only slightly for an instant when that pressure is reached, as the resistance of the spring to still further compression increases with the amount of that compression. The valve would, therefore, open and close continuously, discharging only a little steam each time, and pounding the seat so that the valve or seat would be damaged. But, if the face of the valve is enlarged beyond the seat, it will be seen that, as soon as the valve begins to open to the pressure, the escaping steam acts on an increased area; therefore the opening for the escape of steam is increased suddenly, and the valve "pops" and is held open until the pressure has fallen below the opening pressure.

The adjusting ring is fitted outside of the valve lip to regulate the opening for the escape of steam. The difference between opening and closing pressures is called the "blow down." The position of the adjusting ring governs the amount of this difference. When the adjusting ring is screwed to the highest position, the opening for the escape of steam is made small and the pressure on the under side of the lip approaches the pressure on the valve below the seat. Consequently the valve will remain open until the pressure in the boiler has dropped well below the lifting pressure. Also, when the adjusting ring is screwed down, the opening between the valve

lip, seat bushing, and adjusting ring is increased in size, the steam escapes more freely, and the pressure on the under side of the valve lip is reduced. Therefore, the valve will reseat as soon as the pressure has dropped a little below its opening pressure.

All safety valves in general use operate on the principle of the one shown in the figure. Safety valves patented by and manufactured by different companies, differ among themselves in the method of applying compression to the spring, the method of transmitting the spring pressure to the valve, the shape of the valve lip and adjusting ring, and the method of adjusting the position of the adjusting ring and locking it in position.

When one valve on a boiler is being set and lifted by steam to test the lifting pressure, the other valves on the same boiler are held on their seats by gags. A safety valve gag is a clamp which is fitted over the top of the valve spindle, attached to the valve body, and screwed up so as to hold the valve down on its seat.

Setting valves.—

(1) Check boiler steam gage with test gage or gage testing machine. (2) Gag all valves on the boiler except the one to be set. (3) Disconnect hand lifting gear, remove key and cap from top of valve spindle. (4) Turn compression screw right handed (down) to increase spring pressure and consequently to increase the lifting pressure of the valve. A rough idea of how much the compression screw is to be moved up or down can be obtained from the position of the scribe mark on the top spring washer with respect to the vernier plate which is graduated in pounds per square inch. (5) Handle fires to increase steam pressure in boiler to lifting pressure. Note pressure on steam gage at which safety valve lifts and also pressure at which it reseats. (6) Re-adjust compression screw up or down and test again with steam until correct lifting pressure is obtained. (7) Set up compression screw nut. (8) The difference between lifting and reseating pressures (blow down) should be about five pounds. If the difference in pressures, noted on the steam gage, was greater than this, back out the adjusting ring lock pin, insert a small screw driver or other instrument through the hole and turn the adjusting ring until it has moved down a small amount. Replace lock pin. (9) Test again with steam and re-adjust the adjusting ring until, by trial and error, the proper blow down has been obtained. (10) Gag this valve and go ahead with the same procedure on the other valves of the same boiler until all have been adjusted. (11) Replace caps and keys. Connect up hand lifting gear and test hand lifting gear to see that all valves lift by hand. The hand lifting gear is shown in the right side of the figure. When the shaft is rotated the system

of levers lifts up on the cap, which is keyed to the valve spindle. As the valve spindle is also keyed to the valve, the valve is lifted from its seat. The hole through the end of the 'cap' key is for a small padlock to prevent unauthorized persons from tampering with the safety valve setting.

The vernier plate can be shifted up or down slightly. It is a good practice, after a valve has been set and tested under steam, to move the vernier plate up or down until the index mark on the top spring washer is opposite the graduation on the vernier plate corresponding to the pressure at which the valve was noted to have lifted under steam. This will be of considerable assistance when it again becomes necessary to set the valve.

Water gages.—A water gage is a column in which the water is visible. One end is connected to the steam space and one to the water space of the boiler.

Two general types of water gages are in use:

- (1) The "Scotch" or annealed-glass tube.
- (2) The metal column with a glass plate at the front or at the front and back. There are many patented varieties of this type.

In both types the top and bottom of the tube or column are secured by stuffing boxes to the upper and lower valve bodies which are connected to the boiler. The upper valve body contains a shut-off valve or plug cock, by means of which the upper connections to the boiler may be shut off, and an automatic self-closing valve of either the cone seated check or ball check type. The lower valve body contains a similar shut-off valve or plug cock and self-closing valve and, in addition, a cone seated "blow-out" or drain valve.

Figure III-7 shows the "star" gage glass. The automatic valves and the shut-off valves are shown open. It will be seen that there is a seat for the automatic valve and another one, opposite this, for the shut-off valve. The ball in the "star" gage rolls down the slightly conical surface when in equilibrium. So long as there is equilibrium of pressure within the water gage, this automatic ball valve does not move. But if the glass breaks, there will be a rush of steam and hot water into the fireroom, and, owing to the difference in pressure, the ball will be forced against the seat and the flow of steam or water cut off. The amount of steam and water blown out will thus be very small, and the shut-off valves can be closed by hand without danger of scalding. (The stem of each shut-off valve ends in a pin projecting beyond its seat, by means of which the ball is pushed back to its normal position as the shut-off valve is closed.) A new glass can then be put in by slacking back the stuffing box nuts. A guard of wire gauze is fitted around the glass to catch any small pieces of glass in case of breakage.

To install a new glass in a "Scotch" type gage the stuffing box nut,asher, and one or two rubber rings or grommets are placed around the glass at each end. Care must be taken in setting up the stuffing box nuts to get the glass tube out of line. If there is any twisting or bending in the glass, the glass will break as soon as the shut off cocks are opened to admit steam and water. Spare glass tubes are packed in individual paper boxes and should be kept in these boxes until they are installed. Any abrasion on the glass will tend to make it break quickly.

Figure III-8 shows a "Dewrance" water column with plate glass at the front and back.

Figure III-9 shows the outline of the water and steam chambers at the bottom of a "Dewrance" water gage. When the pressure is in equilibrium the ball check valve rests in the recess of the holder. When the glass breaks the rush of water carries the ball up against the seat and shuts off the water. Then when the plug cock is closed, shutting off the pressure, the ball drops down on its holder again. As shown in the figure, the drain valve is an ordinary cone seated stop valve. The fitting at the upper end has a similar plug cock but the automatic valve is an ordinary cone seated check valve instead of a ball-type check valve.

Most naval service boilers are designed so that the proper gage glass level is half full. As there are many exceptions to this rule the engineer officer determines the proper normal water level by studying the ship's drawings, or if the information cannot be obtained from the drawings, by referring the question to the Bureau of Engineering.

If either the top or the bottom connections of a water gage glass are closed or partially blocked, as in Figure III-7, a piece of scale, the water level indicated is a false one. Therefore the water gage glasses must be blown before connecting the boiler to the steam and at least once an hour thereafter.

The gage glass is blown by closing the top shut-off valve and opening the drain valve, thus cleaning the bottom connection and then opening the top shut-off valve, closing the bottom shut-off valve, and opening the drain to clear the top connections. After blowing care must be taken to see that



FIG. III-7.

both shut-off valves are opened wide and that water level indicated is accurate.

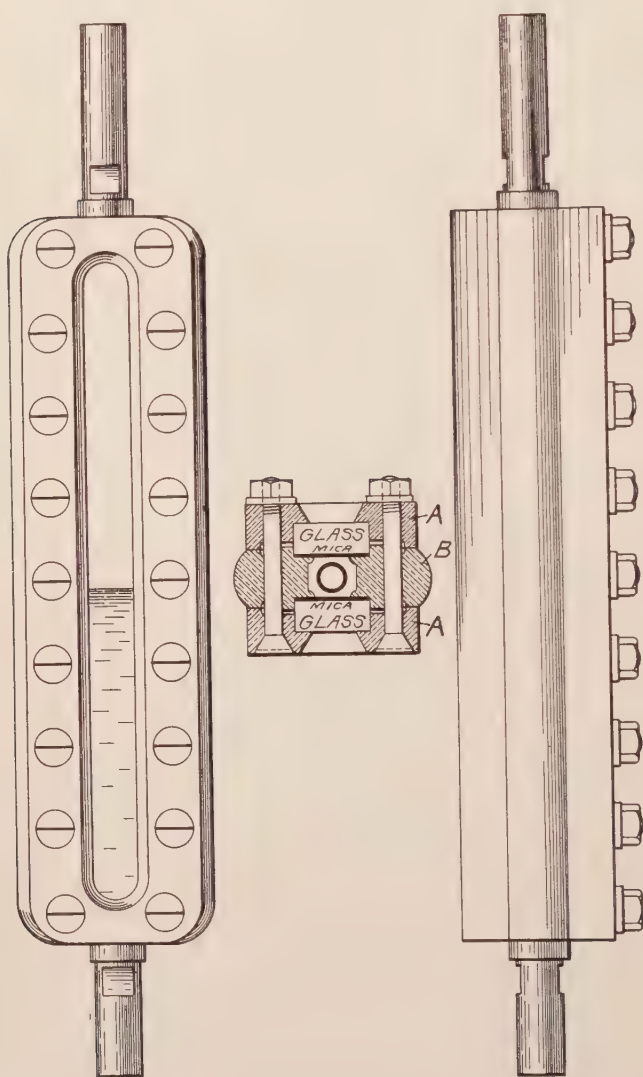


FIG. III-8.—Dewrance Mica-Lined Water-Gage Glass.

Location of water gages.—

(1) The lowest visible part of the water gage is not less than two inches above the lowest permissible water level.

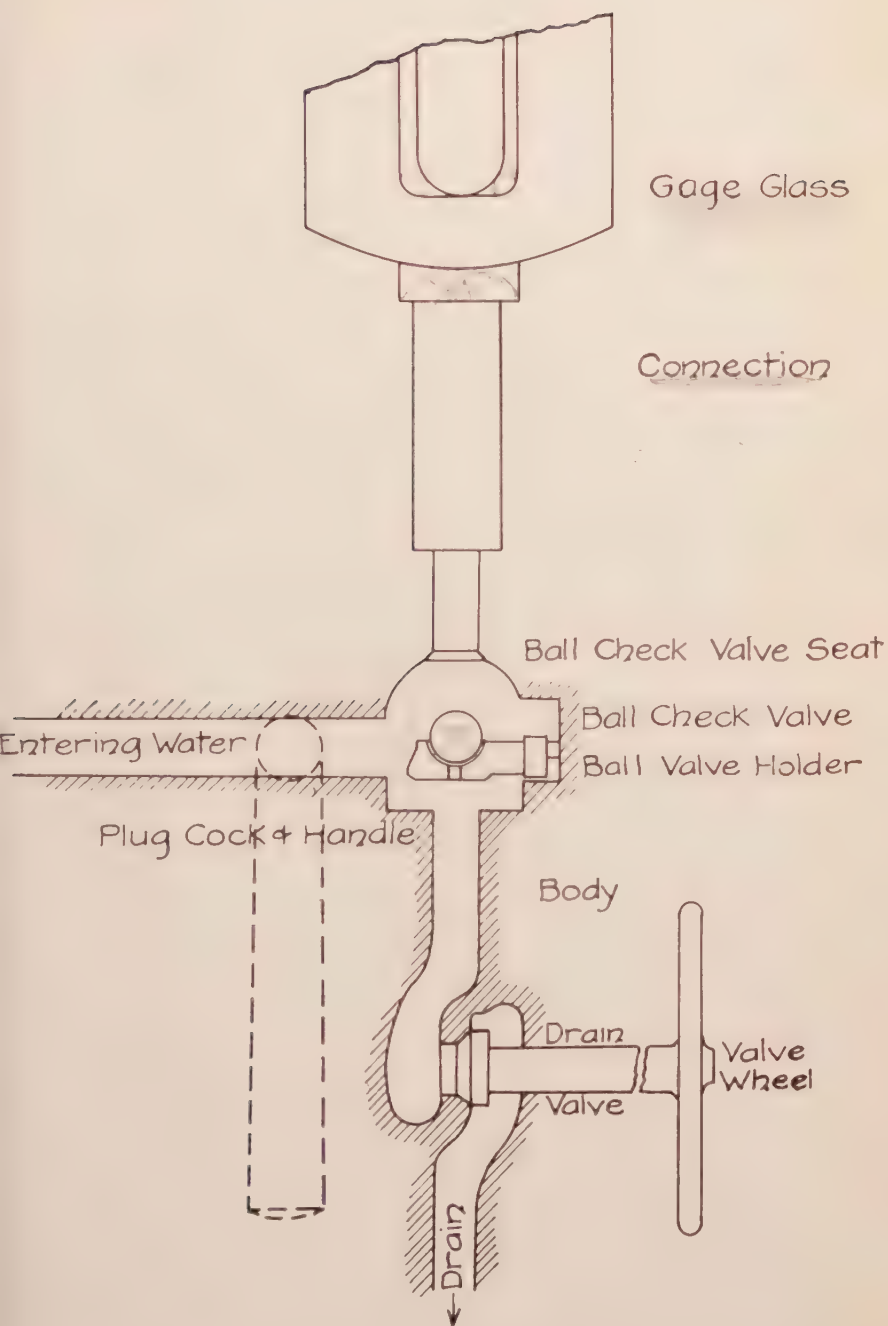


FIG. III-9.—Dewrance Water-Gage Fitting Assembly.
(Sketch shows merely the outline of water and steam chambers.)

(2) The center of the visible length is at the normal working water level.

(3) The connections to the steam drum are vertically spaced, eighteen inches from center to center.

(4) The two gage glasses are installed at points equidistant horizontally from the vertical center line of the boiler and the centers of the connection fittings are on the same horizontal lines. (See Fig. III-5.)

Gage cocks or "try cocks" are used to check the accuracy of the water level indicated by the gage glass. They must be used before connecting the boiler to the steam line and every fifteen minutes while the boiler is in use. Three try cocks are fitted on each boiler and are so located that the vertical distance between the centers of the connections is not less than three inches. The upper gage cock should always show steam, the

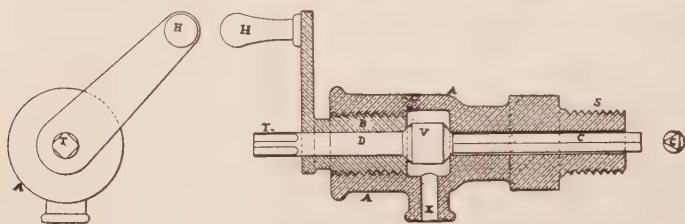


FIG. III-10.—Gage Cocks.

lower one water, and the middle one steam or water or both, depending upon the water level carried in the boiler. An experienced water tender can get a fairly accurate idea of the water level in the boiler by sound and appearance of the blast from each cock.

Fig. III-10 shows a pattern used in our Navy. *A* is a composition valve chamber which is screwed into the boiler or drum by the standard pipe thread *S*. The valve *V*, its spindle *D*, and guide *C* are turned from one piece of rolled manganese bronze or Tobin's metal. The guide *C* is triangular in section, and the spindle *D* is circular where it passes through the movable seat *B*, and square at the end *T*. The valve has two faces. The inner seat for the valve is formed in the casting *A*, and the outer one in the block *B*, which can be screwed in and out by the handle *H*.

The valve is closed by screwing in *B*, and opened by the steam pressure when *B* is screwed out. The opening of the valve is at least three-eighths inch in diameter, and that of the discharge at *X* at least one-fourth inch. By a wrench at *T*, the valve can be turned and the passage around *C* be kept clear. The movable seat serves as a stuffing box, but in a more efficient and safer manner.

Location of gage or try cocks.—The gage cocks are located so that the vertical distance between the centers of the connections is not less than three inches. The lowest cock is located as directed by the Bureau of Engineering for each type of boiler. It is usually about two inches below the lowest visible part of the water gage glass; that is, it is at the lowest permissible water level. (See Fig. III-5.)

Soot blowers.—The soot blowers are sections of heavy steel pipes or tubes located between the boiler tube banks. Each soot-blower pipe is fitted with steam or air nozzles, is connected to an operating head outside the boiler, and is fitted with gearing which revolves the soot-blower pipe slowly in its bearings. The steam or air connections are designed so that the steam or air is turned on or off by the operation of revolving the soot-blower pipes, so that steam or air is admitted only when the nozzles are in position for cleaning the heating surfaces.

CHAPTER IV

BOILER ACCESSORIES

The boiler accessories in a marine boiler plant may be classified as follows:

(1) **Feed accessories**, those used to supply pure feed water at a proper temperature and pressure to the boiler, and to maintain a proper level of water in the boiler. These consist of:

<i>Feed and filter tanks</i>	<i>Grease extractors</i>
<i>Reserve feed tanks</i>	<i>Air extractors</i>
<i>Feed suction and discharge pipes</i>	<i>Feed pumps</i>
<i>Air chambers</i>	<i>Condensing and evaporating plants</i>
<i>Feed-water heaters</i>	

(2) **Steam accessories** which convey the steam from the boiler to the main engines and auxiliaries. These consist of:

<i>Main and auxiliary steam pipes</i>	<i>Expansion joints</i>
<i>Cut-out valves</i>	<i>Steam traps</i>
<i>Reducing valves</i>	<i>Separators</i>
<i>Pipe supports</i>	

(3) **Firing accessories**, used in supplying fuel and air to the boiler, in working fires, in removing ashes, and in cleaning fire sides of boilers. These consist of:

(a) For all boilers—

<i>Soot blowers</i>	<i>Tube brushes and cleaners</i>
<i>Soot scrapers</i>	<i>Forced-draft blowers</i>

(b) For coal-burning boilers only—

<i>Dampers</i>	<i>Time firing device</i>
<i>Firing tools</i>	

(c) For fuel-oil-burning boilers only—

<i>Fuel-oil tanks</i>	<i>Fuel-oil heaters</i>
<i>Filling and transfer main</i>	<i>Fuel-oil strainers</i>
<i>Service tank connection main</i>	<i>Atomizers</i>
<i>Service pumps</i>	<i>Air registers</i>
<i>Booster pumps</i>	<i>Burners</i>
<i>Hand pumps</i>	<i>Smoke telegraph</i>
<i>Fuel oil purifiers</i>	<i>Burner control outfit</i>

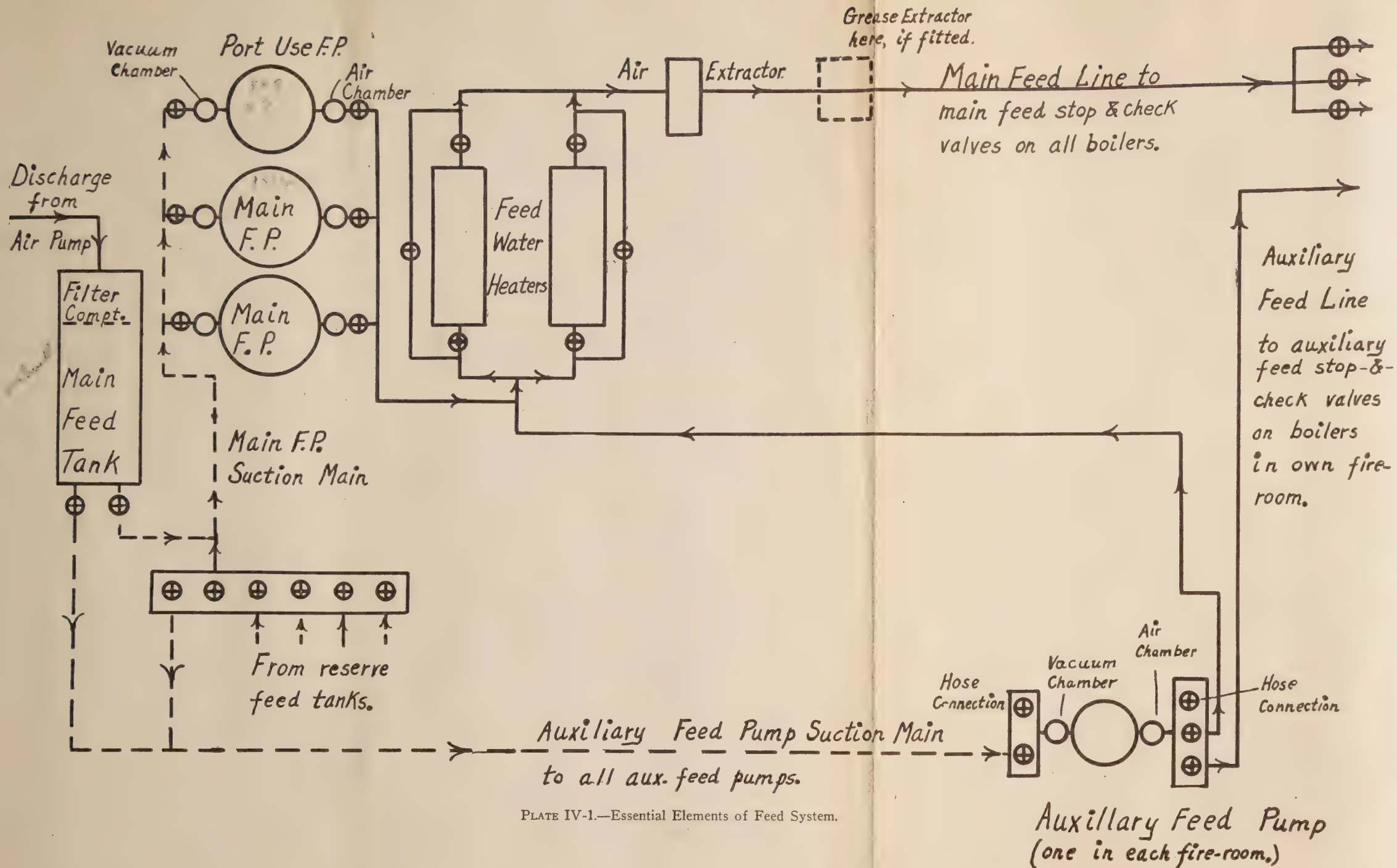


PLATE IV-1.—Essential Elements of Feed System.

*Auxiliary Feed Pump
(one in each fire-room.)*

4) **Testing accessories**, for making various tests and measurements necessary for intelligent and efficient operation. These consist of:

<i>Thermometers</i>	<i>Pyrometers</i>
<i>Steam calorimeters</i>	<i>Gages</i>
<i>Barometers</i>	<i>Pneumometers</i>

I. FEED ACCESSORIES

Figure IV-1 is a diagram of the essential elements of a feed system.

Feed and filter tanks.—The fresh water drawn from the condenser is discharged by the air pump or condensate pump into the filter compartment of a combined feed and filter tank. In large vessels there is a feed and filter tank in each engine room, in destroyers and some other small vessels only one feed and filter tank is fitted and all air pumps discharge into it. The filter compartment is located in the upper part of the tank, is separated from the feed tank proper by a horizontal plate, and is divided into several filtering chambers by vertical plates, alternately secured to the top and bottom of the filter compartment. The filtering material most commonly used is a fibrous marine growth called "loofa" sponges. Bags of charcoal or excelsior or bundles of burlap are sometimes used. The vertical plates force the water to flow back and forth through the filtering material until it flows from the last filter chamber through an opening in the bottom of the filter tank into the feed tank below.

A large pipe connects the bottom of the feed tank to the main feed pump suction main, the auxiliary feed pump suction main, and the "port use" pump suction pipe. The suction pipes from the feed and filter tanks are cross connected but cut out valves are fitted so that the tanks can be isolated.

Figure IV-2 is a diagrammatic sketch of a feed and filter tank with connections.

The feed and filter tanks are fitted with the following connections and fittings:

Filter compartment:

-) Air pump discharge pipes.
-) Vapor vent pipe to atmosphere.
-) Trap drains.
-) By-pass valve and pipe from filter compartment to feed tank for use when the filter is clogged.

Feed tank:

-) Vapor vent pipe.
-) Overflow pipe, usually leading to a reserve feed tank through a scum el visible from the floor plates.

- (3) Trap discharge main.
- (4) Special trap discharge pipes from certain auxiliaries and heaters.
- (5) Drain cock with pipe to a reserve feed tank and a separate discharge to the bilges.
- (6) Gage glass with graduated measuring scale. This may be fitted near the main feed pumps.
- (7) Thermometer.
- (8) Zinc protectors.

Boiler compound tank.

Feed and filter tanks are usually clothed and lagged. For economical operation the temperature of the water in the feed and filter tank should be as high as possible without making the feed pumps lose suction (about 180° F.). For this reason sufficient traps should be allowed to discharge into the feed and filter tank to maintain the temperature. This tank is frequently called the "hot well."

Reserve feed tanks.—Certain double-bottom compartments under engine rooms and firerooms and certain cofferdams are designed for reserve feed tanks. Each reserve feed tank has a suction pipe leading to a suction manifold which has the following connections:

- (1) To auxiliary feed pump suction main.
- (2) To main feed pump suction lines.
- (3) To make-up feed pump suction line.
- (4) To condensers.

A pipe leads from each reserve feed tank to a discharge manifold which has the following connections:

- (1) From auxiliary feed pumps.
- (2) From distiller main.
- (3) From filling connections at ship's side.

Each reserve feed tank is fitted with a sounding tube, an air vent, and one or more manholes for access.

Feed suction pipes.—Each main feed pump usually has a separate suction pipe connecting with the main feed tanks and with the reserve feed tank suction manifolds.

An auxiliary feed pump suction main connects all the auxiliary feed pumps and the "port use" feed pump with the main feed tanks and the reserve feed tanks.

Feed discharge pipes.—All of the main feed pumps discharge into a main feed discharge line which runs fore and aft and has branches leading to the main feed stop-and-check valves on all boilers. The main feed pumps discharge into this line through the feed water heaters, air

ractors, and the grease extractors (if fitted). The feed water heaters and grease extractors) may be by-passed. (See Plate IV-1.)

Each auxiliary feed pump discharges direct to the auxiliary feed stop-check valves of the boilers in its own fireroom and also to the main discharge pipe and thence through the feed water heaters and the main feed discharge pipe to the main feed stop and check valve on any boiler. (See Plate IV-1.)

Feed suction pipes are made of copper or seamless drawn steel. Feed discharge pipes are made of seamless drawn steel and tested to twice the boiler pressure. Flanged joints are used for all feed piping.

In order to avoid any restriction to the flow, gate valves are used in both the feed suction and discharge lines. The main and auxiliary feed stop-check valves are exceptions to this rule.

Air chambers.—Each reciprocating feed pump is fitted with a vacuum chamber on the suction side and an air chamber on the discharge side to provide a uniform flow of water to the pump and a cushion on the discharge side to prevent pounding and to insure a steady flow of water to the boilers. The vacuum chamber should be located so as to receive the impact of the column of water in the suction pipe. A by-pass fitted with a relief valve connects the suction and discharge side of all feed pumps. The relief valve is set to open at about 100 pounds greater than boiler pressure.

Feed water heaters.—A feed water heater is a heat transfer apparatus in which the feed water passes through tubes or coils, and is heated by exhaust steam in the shell surrounding the tubes or coils. The exhaust steam is taken from the auxiliary exhaust line. A water seal is maintained at the bottom of the heater shell and a gage glass is fitted to show the height of the water in the shell. The exhaust steam condenses as it gives up its heat to the feed water and the condensed water is discharged through a trap to drain line leading to the condensers and the feed and filter tank. The trap may be by-passed if inoperative.

Formerly some feed heaters were low-pressure heaters; that is, they were placed on the suction side of the feed pumps. This limited the feed temperature to about 180° F., where the pumps would lose suction. All modern feed heaters are now high-pressure heaters, placed on the discharge side of the feed pumps and the feed temperature is limited to that obtainable from the auxiliary exhaust steam. The Navy requirements are that the auxiliary exhaust steam should not exceed ten pounds gage or twenty-five pounds absolute pressure. The temperature of the steam at twenty-five pounds absolute pressure is 240° F. With a clean feed water heater, properly operated, temperature of the feed water can be maintained at 2° F.

below that of the exhaust steam at low powers when a comparatively small amount of feed is passing through the heater and and at 10° F. below that of the steam when a comparatively large amount of feed is being heated. It has been found that for every 10° F. rise in feed temperature there is a 1 per cent reduction in the amount of heat necessary to produce the steam and a corresponding saving in fuel. Causes of low feed temperatures are: (1) steam or water side of feed heater coated with grease or

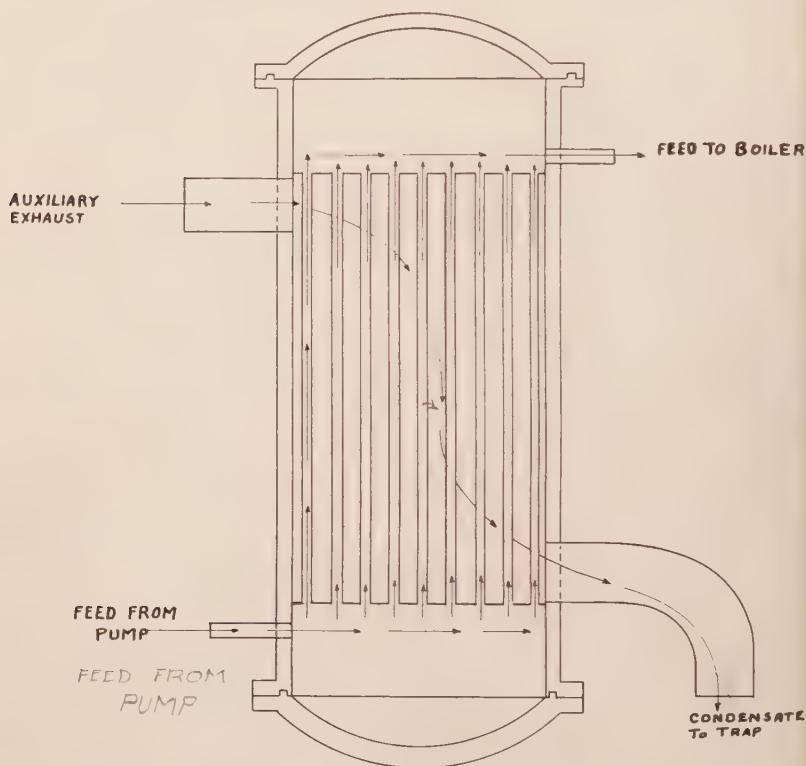


FIG. IV-1.—Straight-Flow Feed Heater. Diagrammatic Sketch.

scale; (2) low back pressure; (3) faulty operation of trap causing high water level in steam side of heater.

Feed water heaters in use in the Navy are classed as follows:

- | | |
|--------------------------|-----------------|
| (1) <i>Straight flow</i> | (3) <i>Coil</i> |
| (2) <i>U-tube</i> | (4) <i>Film</i> |

A straight-flow feed water heater consists of a cylindrical shell of circular cross section, closed at each end by a tube sheet into which are

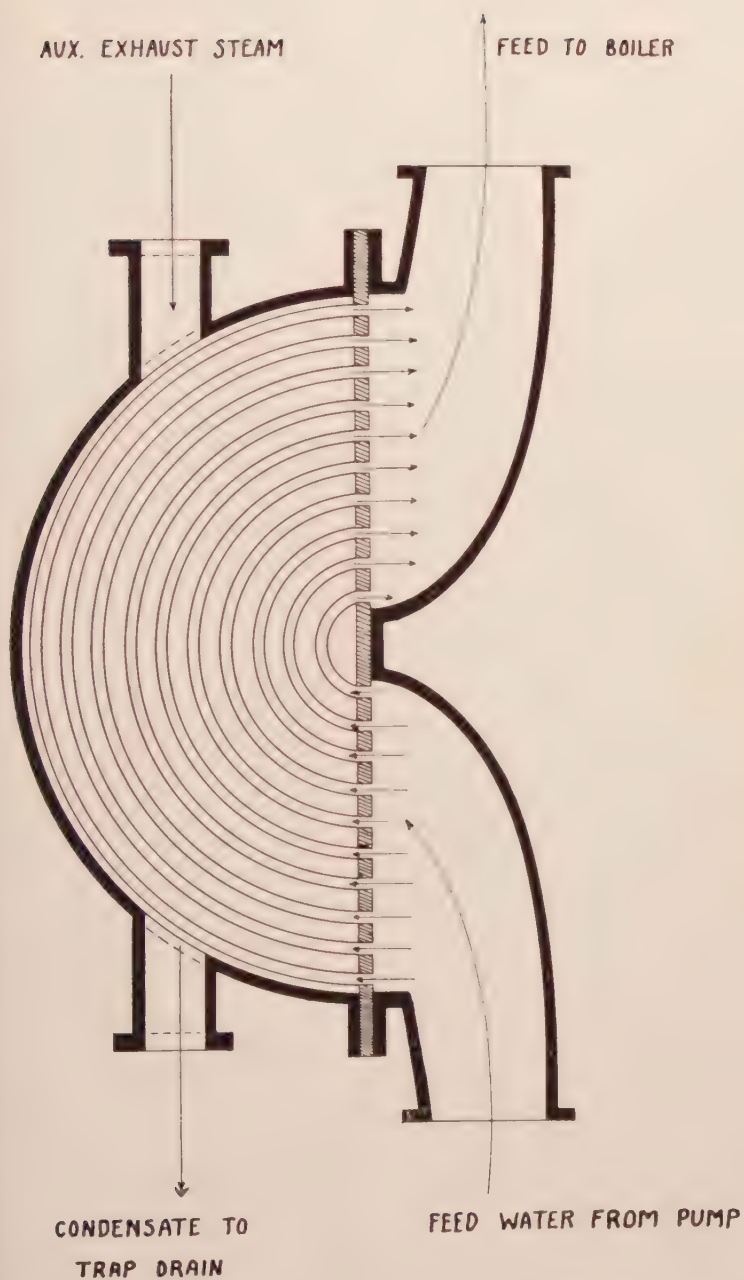


FIG. IV-2.—U-Tube Feed Water Heater. Diagrammatic Sketch.

expanded the tubes. Water heads are bolted onto the shell at each end outside of the tube sheets. Steam from the auxiliary exhaust line fills the shell and surrounds the tubes through which the feed water passes. The feed water flows through the tubes, from one water head to the other. Figure IV-1 is a line sketch of a single pass heater. The water heads may be divided by diaphragms to make the feed water flow from one water head to the other two or more times. In one type there are six such "passes" of the feed water.

Expansion is allowed for by allowing one tube sheet to slide in a stuffing box or by using a corrugated copper shell. The shell should be well lagged.

Some straight-flow feed heaters are fitted with *retarders*. A retarder is a flat strip of brass, twisted into helices at regular intervals along its length. The retarder is of the same length as a tube, is inserted in the tube, and is secured at one end. The feed water passing through the tube is given a whirling motion by the retarder which increases the efficiency by agitating the water and breaking up the non-conducting film which tends to form at the tube surface.

The U-tube heater has tubes bent into U-shape with both ends expanded into the tube sheet. The shell is a short cylinder of semi-circular cross section. The water heads are bolted onto the two halves of the tube sheet. The heater may be installed with the tubes in a vertical or horizontal plane, but the exhaust steam is always admitted at the top of the shell and the drain to the trap is always at the bottom of the shell. See Figure IV-2 for diagram.

In coil heaters, such as the Reilly Multicoil heater, the tubes are replaced by long helical copper coils which are secured to a manifold at the top and at the bottom of the shell by ground joint unions or by cone or screwed joints. The feed water is admitted to the bottom manifold, passes up through the helical coils to the top manifold and then out to the feed discharge line. The exhaust steam is admitted at the top of the shell and the condensate water is drained out to the trap through a line at the bottom of the shell. (See Plate IV-3.)

Film type feed heater.—Figure IV-3 is a line sketch of a Schutte-Koerting film-type feed heater. The feed water enters the lower water header at the left side. This header is divided into two parts by a diaphragm. The feed water fills the spaces between the inner and outer corrugated tubes, flowing from lower water header to the upper and then back to the lower water header and then out the discharge. The auxiliary exhaust steam enters the shell at the top, surrounds the outer corrugated tubes and flows through the inner corrugated tubes, giving up heat to the feed water in the "film" between the tubes. Water condensed from the steam drops

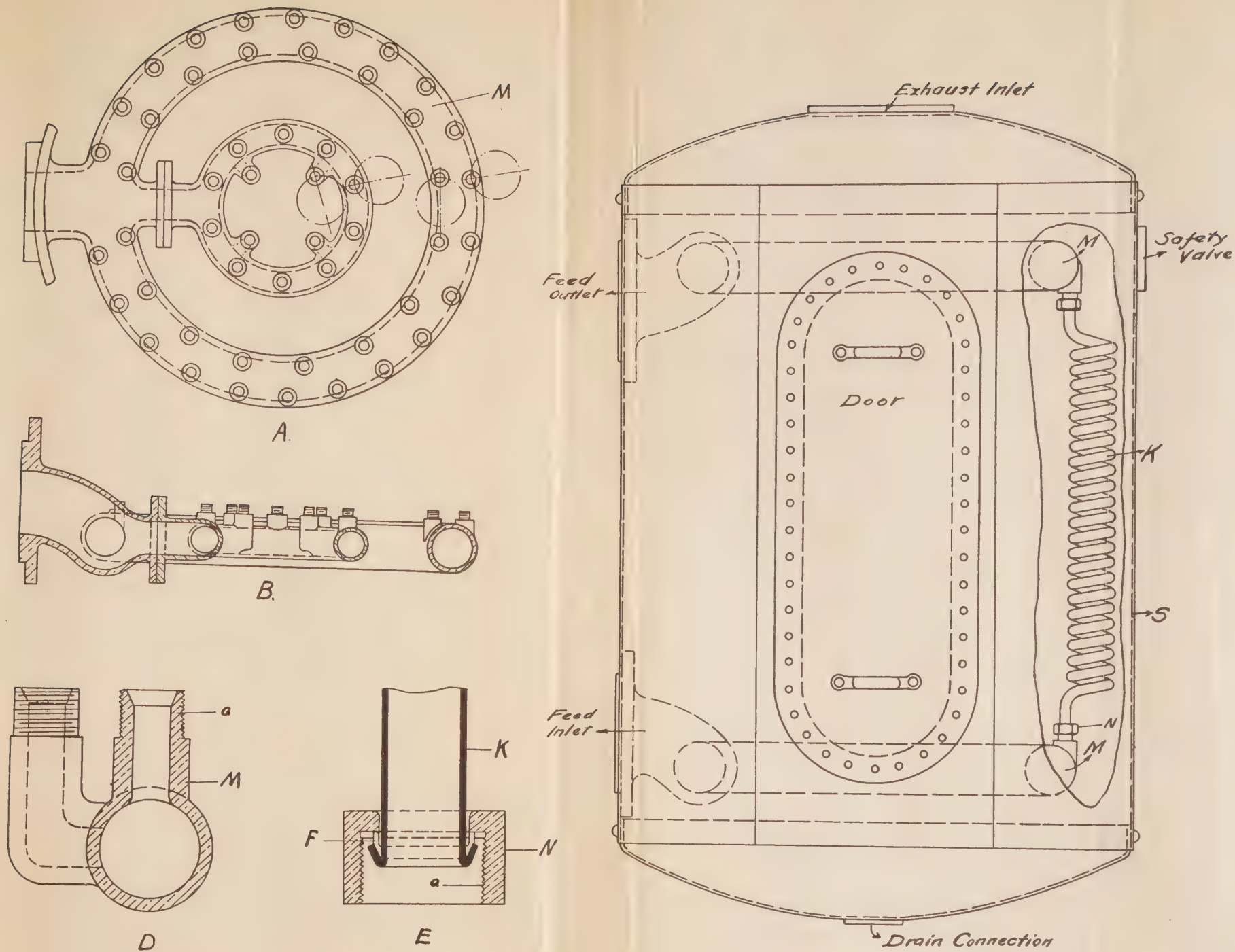


PLATE IV-3.—The Reilly Multicoil Feed Heater.

the bottom of the shell and is drained off through a trap. The gage glass shows the height of water in the shell. The trap drain should be operated to keep some water showing in the gage glass, thus maintaining water seal to prevent the steam from blowing through. An air cock is placed at the top of the shell.

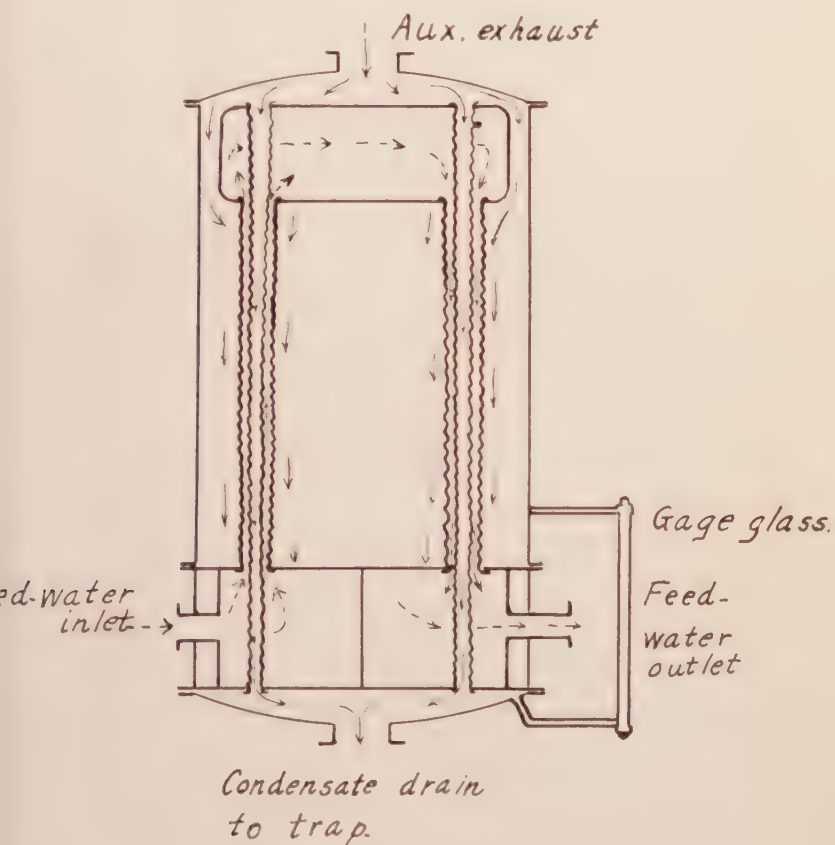


FIG. IV-3.—Film Type Feed Water Heater.

Grease extractors.—The feed suction lines from the feed tanks to the main feed pumps are sometimes fitted with grease extractors. The grease extractor used in the Navy is composed of a casing and a perforated cartridge covered with linen or toweling and filled with loofah sponges. The water enters the casing and finds its way through the filtering material, then passes through the cartridge to the main feed suction pipe. This extractor should be installed double, so that one can be in use while the

other is being cleaned. Where there is much grease in the feed water, the extractor, where installed singly, can be by-passed while it is being cleaned.

Air extractors.—On some ships air extractors are fitted in the highest part of the feed discharge lines near the boilers. As air collects in the air chamber it is blown off through the blow-off pipe. The presence of air in the air chamber is shown by a lowering of the water level in the gage glass on the side of the air extractor. It is very desirable to remove as much air as possible from the feed water because air in feed water has two bad effects: (1) air is a relatively poor conductor of heat and air bubbles cut down the efficiency of the boiler; (2) the oxygen in the air is the most serious factor in the corrosion of the boiler steel.

Feed pumps.—Feed pumps may be classed according to purposes as: (1) "*Main*," (2) "*Auxiliary*" or "*Emergency*," (3) "*Port use*"; or according to type as: (1) *Piston*, (2) *Plunger*, (3) *Rotary*.

The feed pump must be capable of discharging the feed water through the discharge line, feed heater, and air extractor into the boilers against the steam pressure of the boilers. They are usually designed to discharge at about 100 pounds higher pressure than the safety valve pressure of the boilers.

Condensing and evaporating plants.—The condensing and evaporating plants may properly be considered boiler accessories because with the high pressure carried in modern water-tube boilers the purity of the feed water has a most important bearing upon the efficiency of the boiler plant. However the condensing and evaporating plants are included in the textbook on auxiliary machinery and will be omitted here.

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2. STEAM ACCESSORIES

The high-pressure steam generated in the boilers is supplied to the parts of the ship where it is to be used through two general systems of piping known as the **main steam lines** and the **auxiliary steam lines**.

The main steam lines lead the steam from the boilers to the main propelling plant. The main steam piping is fitted with cross connections and **cut-out valves** (stop valves) so that, any boiler, fireroom, or engine room may be cut out without interrupting the supply of steam to or from other units. The cut-out valve located ahead of the throttle is usually placed on the forward bulkhead of the engine room and is generally called the "main engine stop valve" or "bulkhead stop valve."

The auxiliary steam lines lead from the boilers or main steam lines to the various auxiliary machinery throughout the ship. Some parts of the auxiliary steam lines are cross connected and the branches leading to various units are fitted with cut-out valves. Certain branches of the auxiliary

steam piping system are given names to indicate the auxiliary machinery which they supply as: dynamo steam line, evaporator steam line, anchor-gine steam line, etc. The branches of the auxiliary steam piping are also fitted with cut out valves to permit the isolation of individual units for repairs or in case of accident.

The boiler stop valves, cross connection valves, and cut out valves, mentioned above are all fitted with hand wheels so that the valves can be operated from the engine rooms or firerooms, and are also fitted with distant control gear by means of which they can be operated from the deck above in an emergency.

Reducing valves.—Certain auxiliaries, heating systems, galley steam lines, etc., require steam at a constant pressure lower than boiler pressure. This constant low pressure steam is supplied by branches of the auxiliary steam line fitted with *reducing* valves. A reducing valve is a patent valve designed to throttle the steam automatically and to deliver the constant low pressure for which the valve is set, as long as the steam on the high-pressure side of the valve is greater than that desired on the low-pressure side.

Pipe supports.—The main and auxiliary steam pipes are supported by steel hangers secured to the beams overhead and by brackets secured to anchorions or bulkheads. These hangers and brackets must be adequate in number and properly located in order to prevent vibration of the pipes and to carry all of the weight, so that the pipe joints do not have to support the weight of the pipe in addition to their proper function of retaining the pressure. Troublesome pipe leaks can often be eliminated by installing additional hangers or brackets. It must be remembered that the steam and other pipes are not strength members of the ship's structure and must not be used as supports for stages to carry heavy weights, suspension points for chain falls, etc. Where a steam pipe pierces a bulkhead, a special type of flange is usually installed. This flange has a double row of bolt holes, the outer row being used to secure the flange to the bulkhead and the inner row to make up the joint to the adjacent pipe flange. This arrangement eliminates a bracket support at the bulkhead.

Expansion joints.—Provision is made for the expansion and contraction of the steam piping due to changes in temperature by installing expansion joints or expansion bends. Expansion joints are also called "slip joints" and expansion bends are called "U-bends." An expansion joint or expansion bend is installed in every length of straight piping between two points where the pipe is anchored to the ship's structure. Expansion joints are usually fitted at or near a bulkhead and the fixed part of the expansion joint is secured to the bulkhead or a beam overhead.

Fig. IV-4 shows an expansion joint as generally fitted in naval vessels.

A is the stuffing-box casting, generally anchored to the ship's structure; *F* is the gland, with its studs screwed into flange *X* and nuts outside of the gland by which the packing in *S* is adjusted and by which the joint around the sliding pipe *P* is made steam tight. One end of the steam pipe *C* is shown with its flange *Z* bolted to the flange *Y* on *P*; the other end of the main is similarly flanged and bolted to the flange *K* at the opposite end of *A*. To prevent the sliding pipe *P* from drawing out of *A*, **T**-headed stop bolts *B* are fitted between flanges *X* and *Y*. Bolts *B* slide through holes in flange *X* with a loose fit, the **T**-head being placed on the right side of flange *X*.

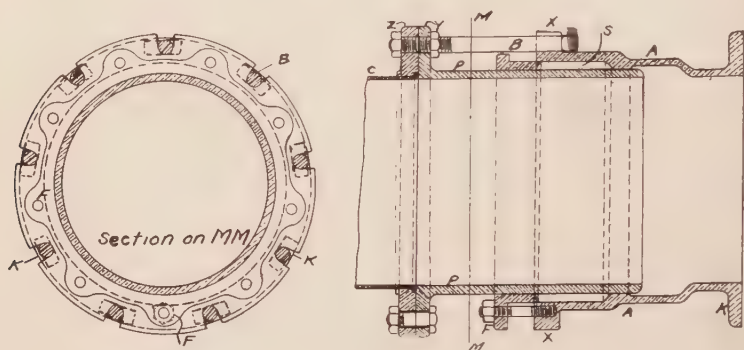


FIG IV-4.

In some expansion joints there are nuts on both sides of the flange *X*; the one on the right side is adjusted to be just clear of the face of *X* with the pipe cold, and that on the left of *X* to be just clear of *X* with the maximum steam pressure in *C*; the nuts at flanges *Y* and *Z* are set up hard against the faces of the flanges.

Expansion joints exposed to superheated steam are made of cast steel, those not exposed to superheated steam are made of either cast steel or composition. The glands are made of composition. Expansion joints are fitted to all steam, exhaust, and feed piping where there are not ample bends to provide for the expansion. Where there are ample bends and no expansion joints are fitted, the pipes are so fitted as to put them under tension when cold.

Main and auxiliary steam pipes are made according to the following tables:

NOTE.—The following table is taken from the table of pipe materials, Chapter 12, paragraph 30, of the *Manual of Engineering Instructions*, which give data on all piping under the cognizance of the Bureau of Engineering.

<i>Size</i>	<i>Materials</i>	<i>Joints</i>	<i>Water pres. test, lbs. per sq. in.</i>
and above	Steel, seamless drawn tubing	Flanged	
below 2" and above 1/4"	Copper or steel, seamless drawn up to 425° F.; seamless drawn steel for higher temperatures	Flanged	1½ times below pressure
2" and below	Steel, seamless drawn, iron pipe size	Screwed	

Steam traps.—Water may collect in pipes, valves, or other steam spaces from condensation or from the water carried over from the boilers to cause the boilers "prime." This water may cause water hammers in the pipe lines, damage steam cylinders in reciprocating engines, damage blading in turbines, or cause corrosion in turbines. The water is removed by fitting drains to all low places in the pipe lines, valves and other steam spaces. Each drain pipe is connected to an apparatus called a trap which discharges the water to a condenser or feed tank and prevents the escape of steam with the water.

There are four general types of automatic traps:

- (1) *Bucket traps*
- (2) *Float-operated traps*
- (3) *Differential traps*
- (4) *Expansion traps*

The bucket type is generally used on high pressure lines.

The float-operated traps are used for both high and low pressures but the floats are liable to leak under high pressures.

Differential type traps are used on vacuum spaces, especially for draining turbine casings.

Expansion type traps are used for low pressure drains, heating system, evaporator drains, etc.

All traps should be located where they will be accessible for repairs and tests and should be fitted with by-pass pipes and valves to permit the operation of the drains by hand if the traps fail to function.

Separators.—In addition to the traps mentioned above, separators are installed on some pipes to remove water from the steam pipes. They are usually connected in the main steam lines, just ahead of the throttles. The separation of the water from the steam is accomplished in one class of separators by making an abrupt change in direction of the steam and water. In another class this change in direction is accomplished by making



FIG. IV 5.

the steam take a whirling motion producing centrifugal force, by means of which the water is thrown to the sides of the separator and drained off from the separator. Figure IV-5 shows one type of separator.

Escape pipes.—Aft each smoke pipe is a copper escape pipe which connects the safety-valve chambers to the atmosphere. The auxiliary exhaust pipe is connected by a stop valve to one of these escape pipes to permit the auxiliary exhaust steam to escape to the atmosphere whenever this is necessary because of the derangement of the auxiliary condensing plant.

3. FIRING ACCESSORIES

(a) *For all boilers.*

Soot blowers.—The fire sides of tubes are cleaned by (1) blowing, (2) scraping, or (3) washing, or by a combination of two or all methods.

In blowing tubes, a lance is used. The lance is made of a length of small pipe flattened at one end to form a nozzle, and attached to a steam or compressed air hose. When the boiler is in use the tubes can be blown only by speeding up the blowers and inserting the lance through the casing openings provided for the purpose. An idle boiler's fire sides can be cleaned from inside the furnace space by inserting between tubes.

Soot scrapers.—Hard soot deposits on tubes can be removed by scraping. The scrapers should be made of a metal softer than the tubes. Strips of sheet brass make good scrapers. Ordinary file scrapers are likely to injure the tubes.

The fire sides of tubes are washed with hot water under pressure. Temporary troughs of sheet metal and sections of canvas are used to protect the brickwork. The furnace must be dried out by lighting a small fire immediately after the washing method is used.

Tube brushes and cleaners.—The water sides of a boiler, including interiors of steam and water drums and insides of tubes and downcomers, are cleaned by boiling out, washing out, and brushing.

A fairly good tube brush can be made by fraying the end of a wire rope.

Motor driven, sectional bristle wire brushes, with flexible shafting are supplied to ships for cleaning water sides of tubes. Pneumatic and hydraulic turbine tube cleaners fitted with solid steel cutters with serrated edges are supplied to navy yards and repair ships and are to be used only when inspection reveals very thick, hard scale which cannot be removed by the ship's own equipment.

Forced draft blowers.—Forced draft is supplied by high speed centrifugal fans, driven by small steam turbines or electric motors. The blowers are installed in the upper part of the firerooms or in separate blower rooms just above the firerooms. The speed of each blower is controlled,

from the floor plates of the fireroom it supplies, by means of a throttle or electric controller. The blower fan sucks air at its center from the air trunk and discharges the air from its periphery into a trunk leading to the fireroom. The casing which surrounds the fan must fit close enough to prevent loss of air pressure and still leave sufficient clearance to prevent the fan from striking the casing.

(b) *For coal burning boilers only.*

Dampers.—A damper is a heavy door fitted in the uptake of a boiler to reduce the draft. Dampers are not usually fitted in oil-burning boilers. If they are fitted, the dampers must be bolted wide open before the oil-burning boiler is lighted off.

Firing tools used in coal-burning boilers are: The shovel, hoes (heavy for cleaning fires and lighter for handling ashes), pricker (like a large heavy bent-ended "poker"), slice bars (like a heavy straight "poker"), devil's-claw (a heavy rake with five or six prongs).

The "lazy bar" is a removable cross bar placed in supports on the furnace door frame or ash pit door frame to give leverage to lighten the work of cleaning fires or hauling ashes.

Time firing device.—The time firing device is a contrivance for making at definite intervals of time a signal by which the fireman coals the furnace or works the fire. It insures uniform and regular firing of all boilers. The time interval of the signal is varied to suit different rates of combustion at different speeds. The signal is an electrically operated bell and light on the fireroom bulkhead.

(c) *For oil burning boilers only.*

Recent or modernized naval boiler plants will be found to be equipped with the following accessories for supplying clean fuel oil at the proper pressure and viscosity and air at the proper pressure and velocity.

Fuel oil tanks.—*Storage tanks.*—Located in double bottoms and cofferdams adjacent to engine rooms and firerooms. Fuel oil in the storage tanks is heated so as to reduce viscosity to the point where the pumps will take suction; it is usually heated by steam coils located near the suction pipe in the tank. All steam joints inside the tanks are welded to prevent leakage of water into the oil.

Service tanks.—Double bottoms under engine rooms from which oil is taken by a *booster pump* and discharged to a gravity tank or fuel oil service pump. The service pumps may take suction direct from the service tanks. The service tanks are intended to give a ready supply of oil near the pumps. Only the newest installations have service tanks. All fuel oil tanks are fitted with vent pipes, sounding tubes, and steam fire extinguisher connections. The storage tanks on some ships are fitted with the pneumaticator

system which registers the amount of oil in each tank at a gage located in some central place such as the log room. Each tank may be entered by means of one or more manholes. Some tanks are fitted with salt-water connections to expel gases and wash out the tanks; where no such connections are fitted, a salt-water hose can be used.

Gravity tanks.—Fitted with steam heating coils; automatic heat control; electric water detectors. Used to supply oil by gravity to service pumps. No gravity tanks are fitted in some of the older installations.

Filling and transfer main.—This line runs fore and aft from forward to after tanks connecting with all fuel oil tanks. It has suction connections to, and discharge from, booster pumps and suction connection from service pumps in each fireroom.

Service tank connection main.—Connects service tanks in engine rooms with service pumps and booster pumps, and has connection to discharge from small oil purifier tank, if fitted.

Service pumps.—Turbine or motor driven rotary pumps, or duplex piston or plunger steam pumps. *Suctions.* From: (1) gravity tank, (2) booster pumps, (3) service tank connection main, (4) filling and transfer main. *Discharges.* To: service heater and thence to atomizers through meter and strainer.

Booster pumps are used for transferring oil from tank to tank and for supplying oil to the service pumps.

Figure IV-6 is a diagram of fuel oil pump connection.

Hand pumps.—A small hand power pump is located in each fireroom and is used to supply fuel oil at 200 pounds pressure to two burners for raising steam and can be used also to pump water overboard from the storage tanks. Each hand pump can take suction from gravity tanks, service tanks, or storage tanks.

Fuel oil purifiers.—Motor driven centrifugal separators, used to remove water and foreign matter from fuel oil.

Fuel oil heaters.—The service oil heaters are similar in design to feed heaters. They use high pressure steam from the auxiliary steam lines and their drains are led to the feed and filter tank through traps and inspection tanks. Great care must be taken to see that no fuel oil reaches the feed tanks from leaky fuel oil heaters. Each heater is fitted with a by-pass. Five types of fuel oil heaters are in use: (1) film type, (2) coil type, (3) straight-tube type, (4) curved-tube type, (5) U-tube type.

Fuel oil strainers.—Strainers are installed in the fuel oil suction and discharge lines to remove foreign matter which would clog the atomizers. The strainers are of the basket type, covered with coarse-mesh copper wire

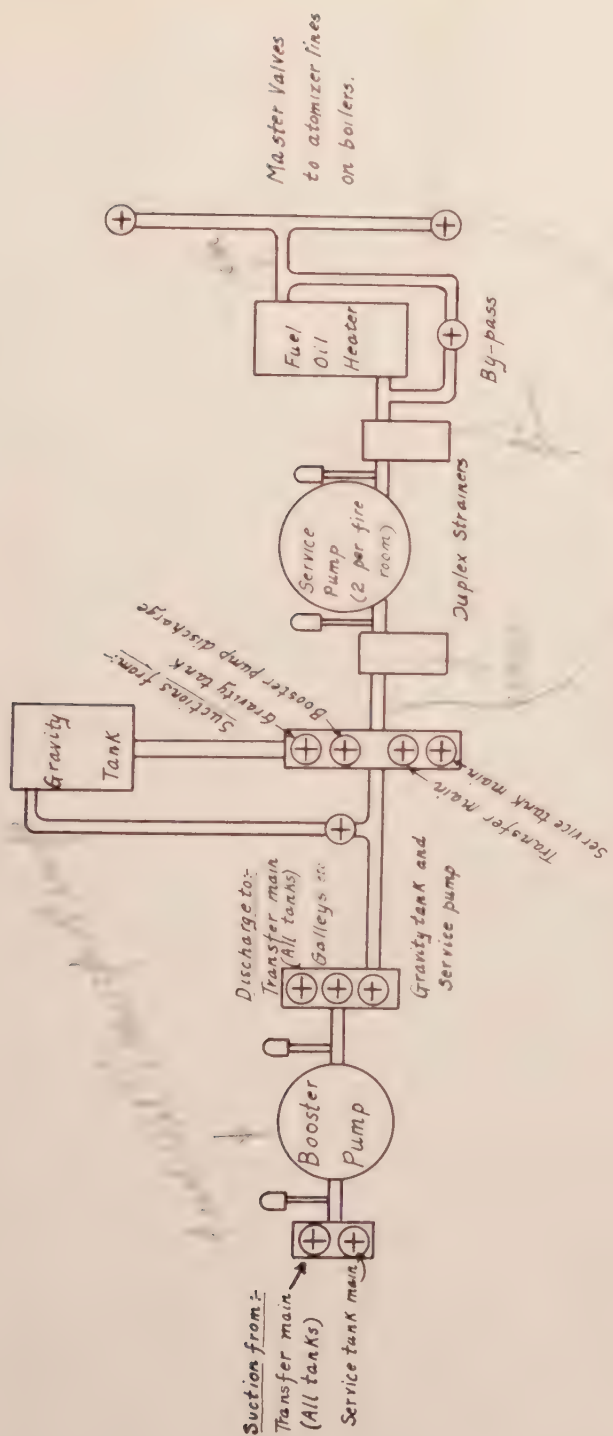


FIG. IV-6.—Fuel Oil Pump Connections.

for the suction strainers and fine-mesh copper wire for the discharge strainers. The oil always passes through the strainer from the inside to the outside of the basket so that the particles are deposited on the inside of the basket. The duplex type of strainer is used. This has a composition strainer body, tested to about 600 pounds per square inch, built in two halves to hold two strainer baskets and fitted with a lever operated cock so that either strainer may be cut out and the basket removed for cleaning. Both strainers cannot be cut out at once. The baskets are cleaned by blowing through with a steam jet. Strainers are always fitted with by-passes so that the supply of oil will not be stopped if the strainers are clogged.

Atomizers.—The three methods of atomizing fuel oil are: (1) *steam atomization*, (2) *air atomization*, (3) *mechanical atomization*.

Oil is supplied to steam and air atomizers at low pressure and the atomization is accomplished by a steam or compressed-air jet which breaks up the oil into fine particles and delivers a mixture of steam and oil or air and oil in a finely divided spray.

Steam atomizers use from three per cent to five per cent of the steam generated by the boiler and are therefore impracticable because of the fresh water loss as well as the low economy.

Air atomization requires air compressors which have large steam consumption, are heavy, take up much room, and require special attention.

For the reasons given above steam atomizers and air atomizers are not used in Navy boiler plants.

Mechanical atomization is accomplished by supplying the fuel oil, of proper viscosity, under high pressure (from 100 to 300 pounds per square inch), to the atomizer, and discharging the oil from the atomizer in a finely divided, cone-shaped spray. The passages in the atomizer and the orifice of the atomizer tip are shaped so as to give the oil a high velocity of rotation, which breaks up the oil by centrifugal force. The rotary motion is obtained by tangential slots from a peripheral passage to the atomizer tip as in the Bureau-type and Peabody-type atomizer. These passages deliver the oil to a cone-shaped chamber, from which it is discharged through the orifice in the atomizer tip.

The amount of oil that can be delivered by an atomizer per hour is called its capacity. This depends upon the pressure and viscosity (controlled by the temperature) and the cross sectional area of the passages in the atomizer.

Large changes in rates of combustion are obtained by cutting burners in or out. Small changes may be accomplished by raising or lowering the fuel oil pressure.

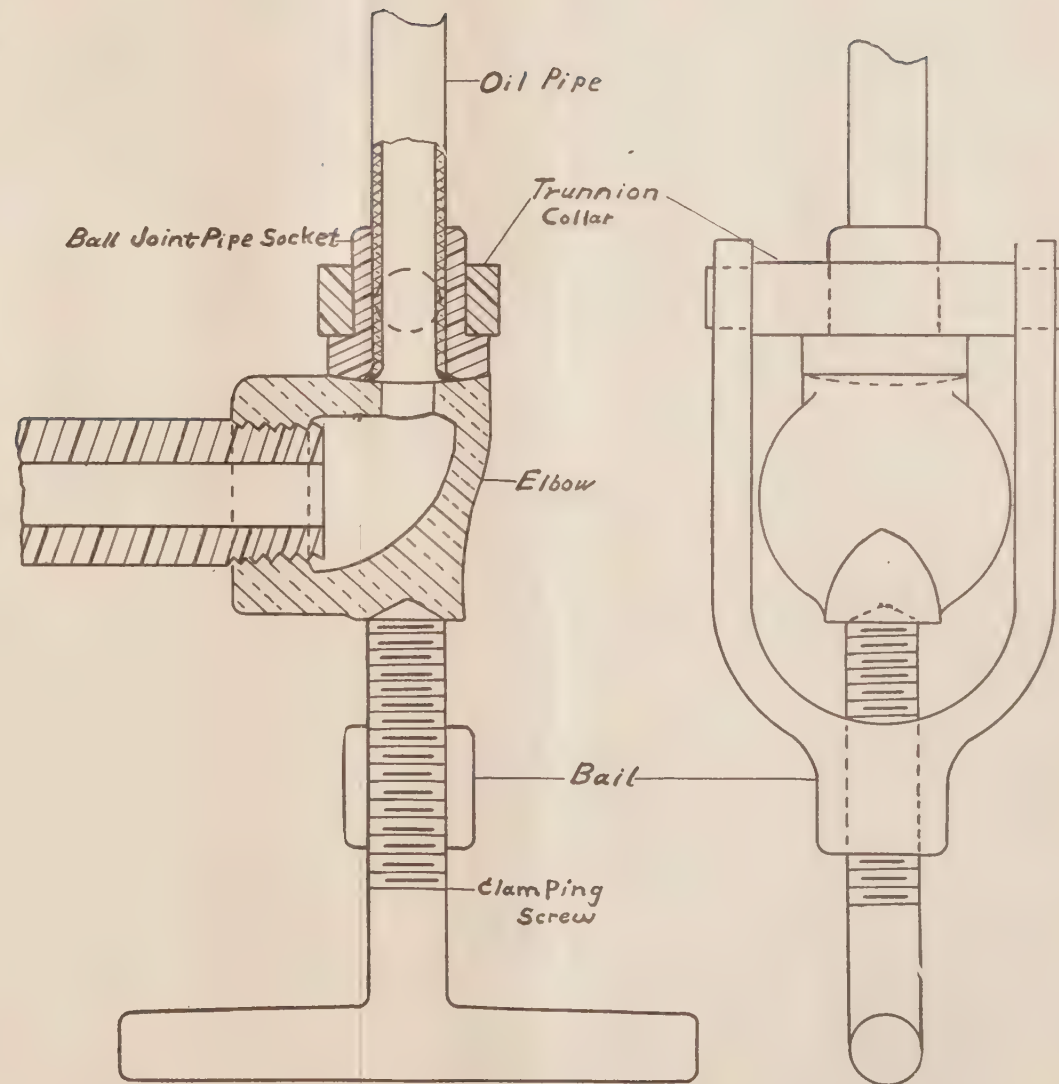
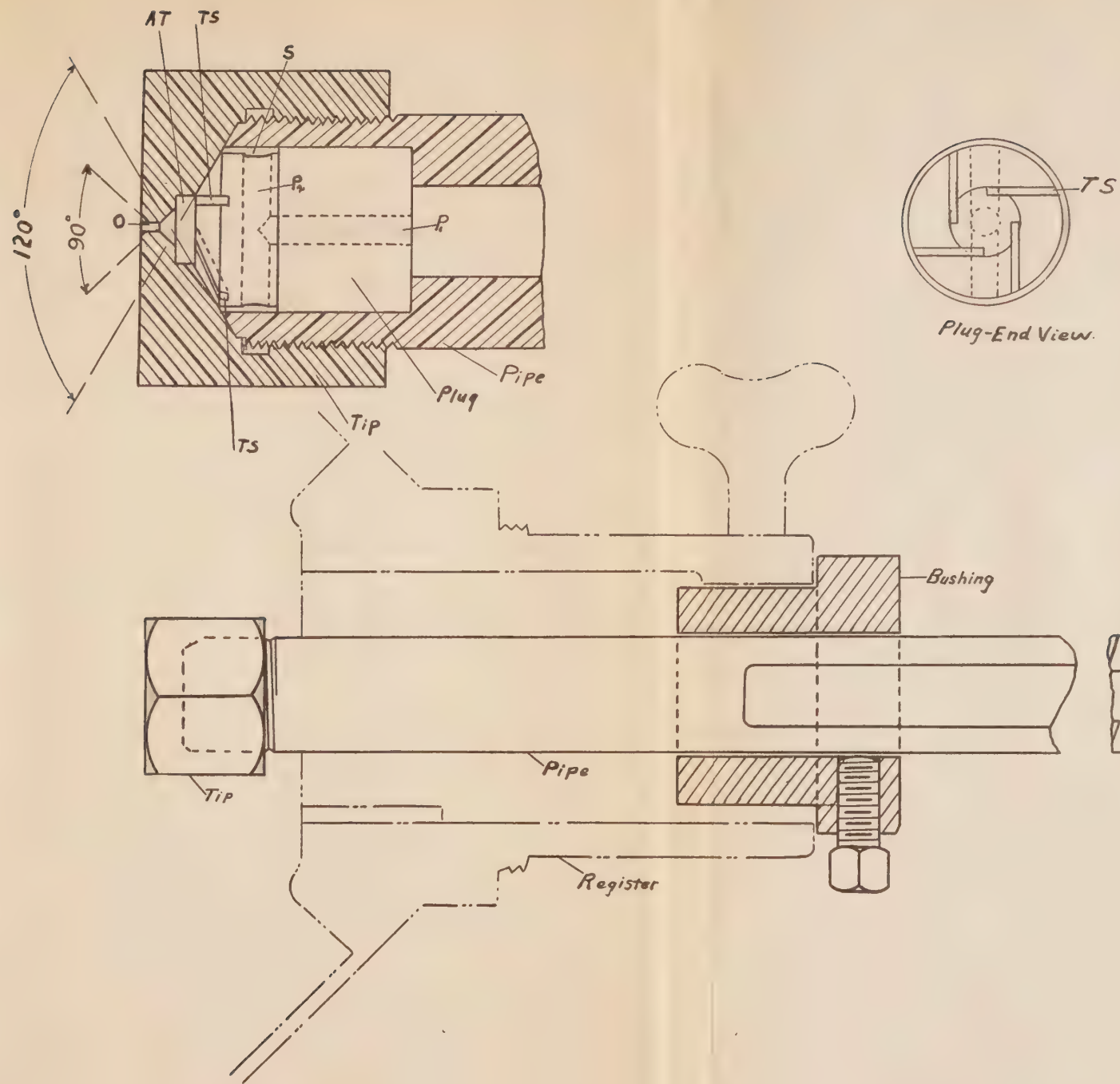


PLATE IV-4.—Bureau of Engineering Standard Fuel Oil Atomizer.

Bureau of Engineering standard atomizer.—The principle of all mechanical atomizers will be understood from a study of the Bureau of Engineering standard atomizer, Plate IV-4.

Oil under pressure from the service pump enters the atomizer through the oil pipe. The atomizer barrel screws into the elbow which makes an oil-tight joint with the oil pipe by means of a ball and socket joint and a clamping screw. The oil passes through the atomizer barrel to the plug. Here it passes through the ports P_1 and P_2 to the annular space S between the end of the plug and the atomizer barrel. This end of the plug is reduced in diameter to form this space. From the annular space S the oil enters four tangential slots TS and is directed inward from S to the cone-shaped atomizing chamber AT in the tip. From the atomizing chamber the oil is sprayed through the central orifice O in a finely atomized cone with very thin walls. Unless the walls of the cone are very thin the oil will not be mixed with the air to give proper combustion. The angle of the oil cone is from 75° to 80° . A slight variation of this angle does not affect the efficiency of the atomizer.

Peabody atomizer—Cuyama type.—Figure IV-7 shows the details of the Cuyama type atomizer. Fuel oil, under pressure from the service pump, passes through the atomizer valve and gooseneck coupling, which are not shown, flows through the extension piece to the nozzle body. The oil flows from the center of the nozzle body through four passages to the annular slot which is cut into the forward face of the nozzle body. The sprayer plate fits closely against the forward face of the nozzle body. Four tangential slots, cut in the after face of the sprayer plate, carry the oil from the annular slot in the nozzle body to the central nozzle chamber of the sprayer plate from which the oil is sprayed in a hollow cone. The burner tip serves merely to hold the sprayer plate firmly against the nozzle body so as to make an oil tight, metal-to-metal joint, and to protect the smooth face of the sprayer plate against scratches and burrs. The sprayer plates are renewed when scratched or marred, or when the tangential slots or nozzle chambers have been enlarged by wear. The oil is broken up and discharged in the hollow cone by the centrifugal force caused by the rapid change of course of the oil, passing from annular slot through tangential slots to the cone-shaped nozzle chamber.

Air registers.—The apparatus through which air is admitted to the furnace of an oil burning boiler is called an air register. The atomizer is located at the center of the air register. The air register performs three functions:

- (1) Gives the air a whirling motion and delivers it through a cone-

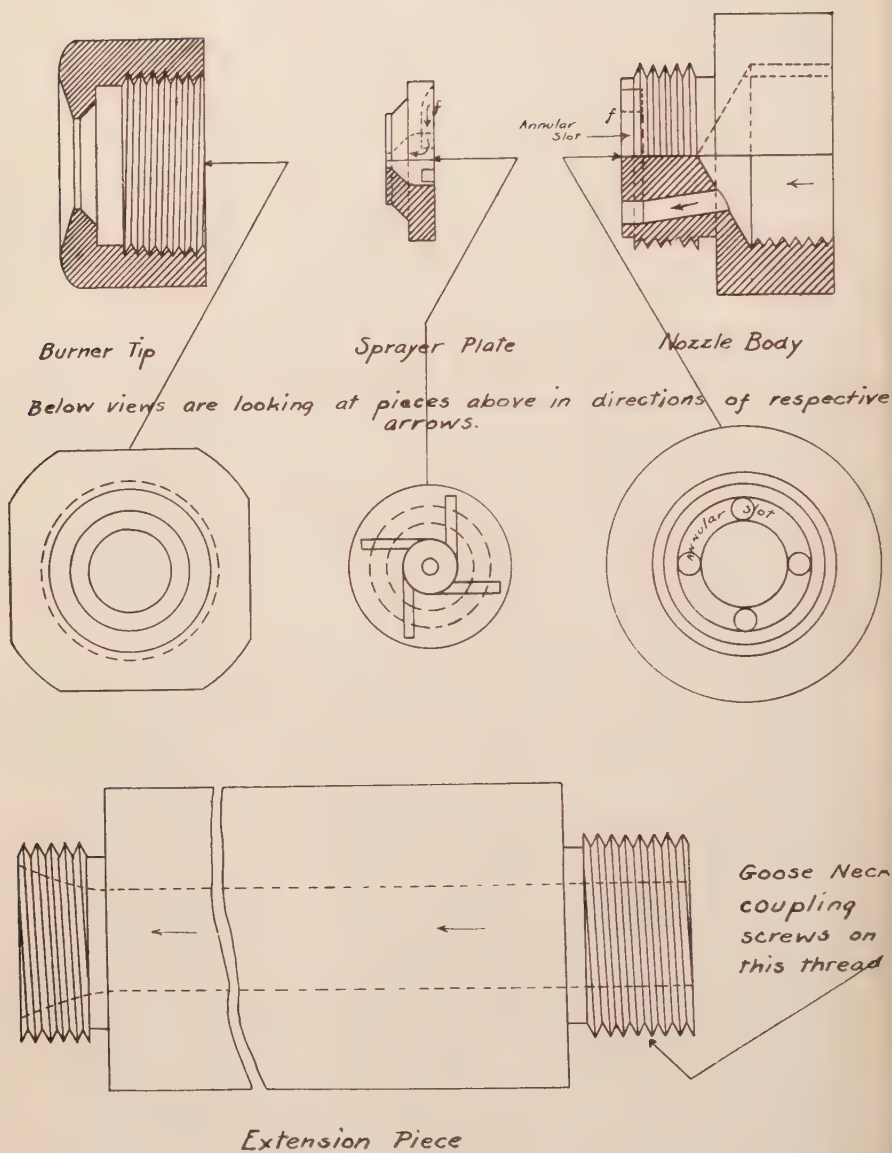
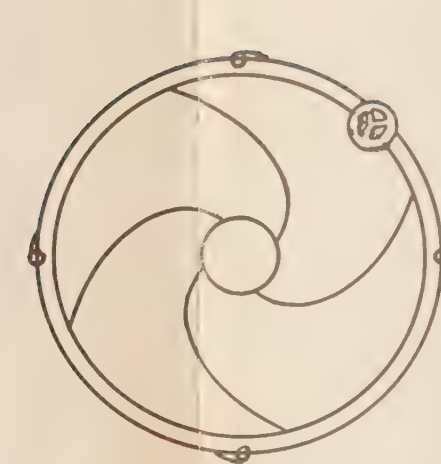
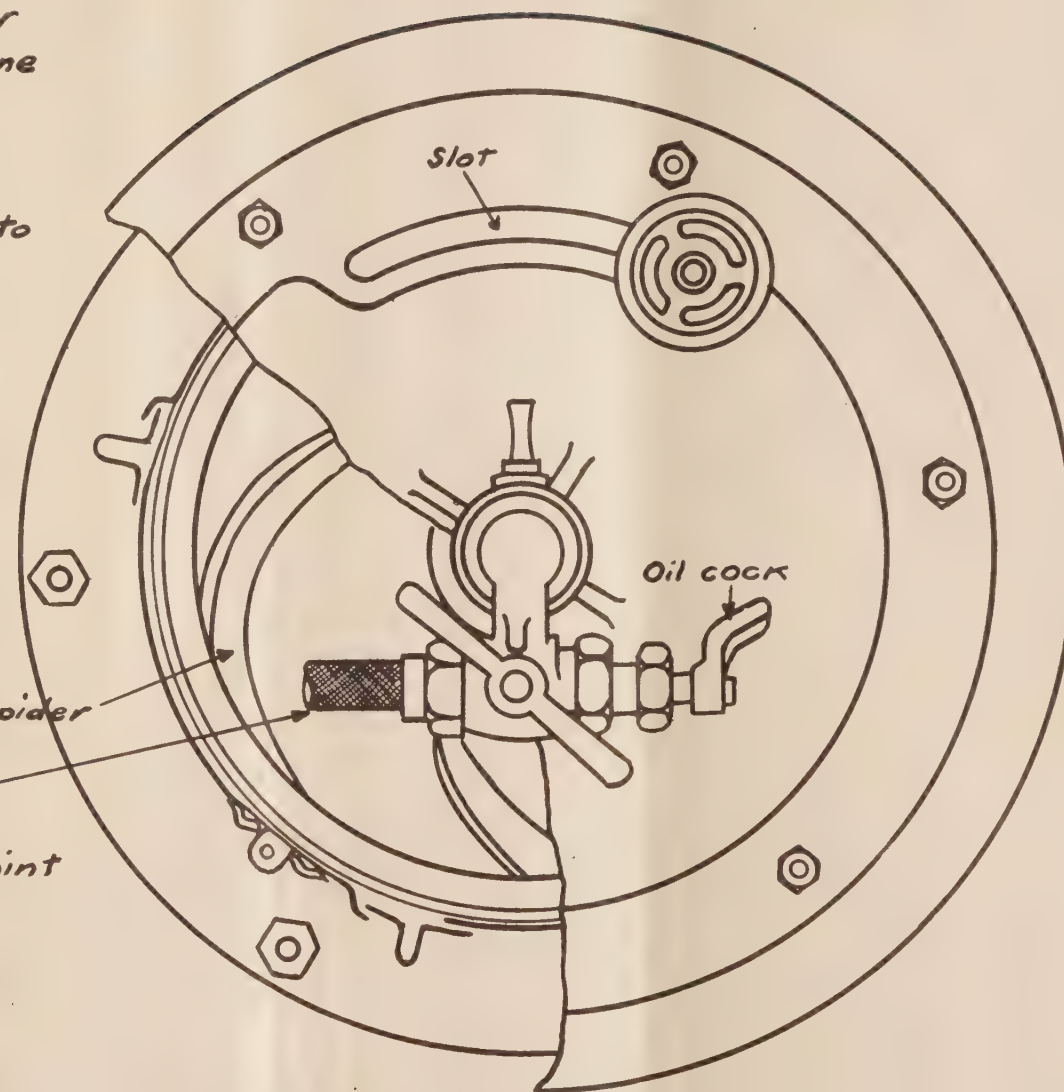
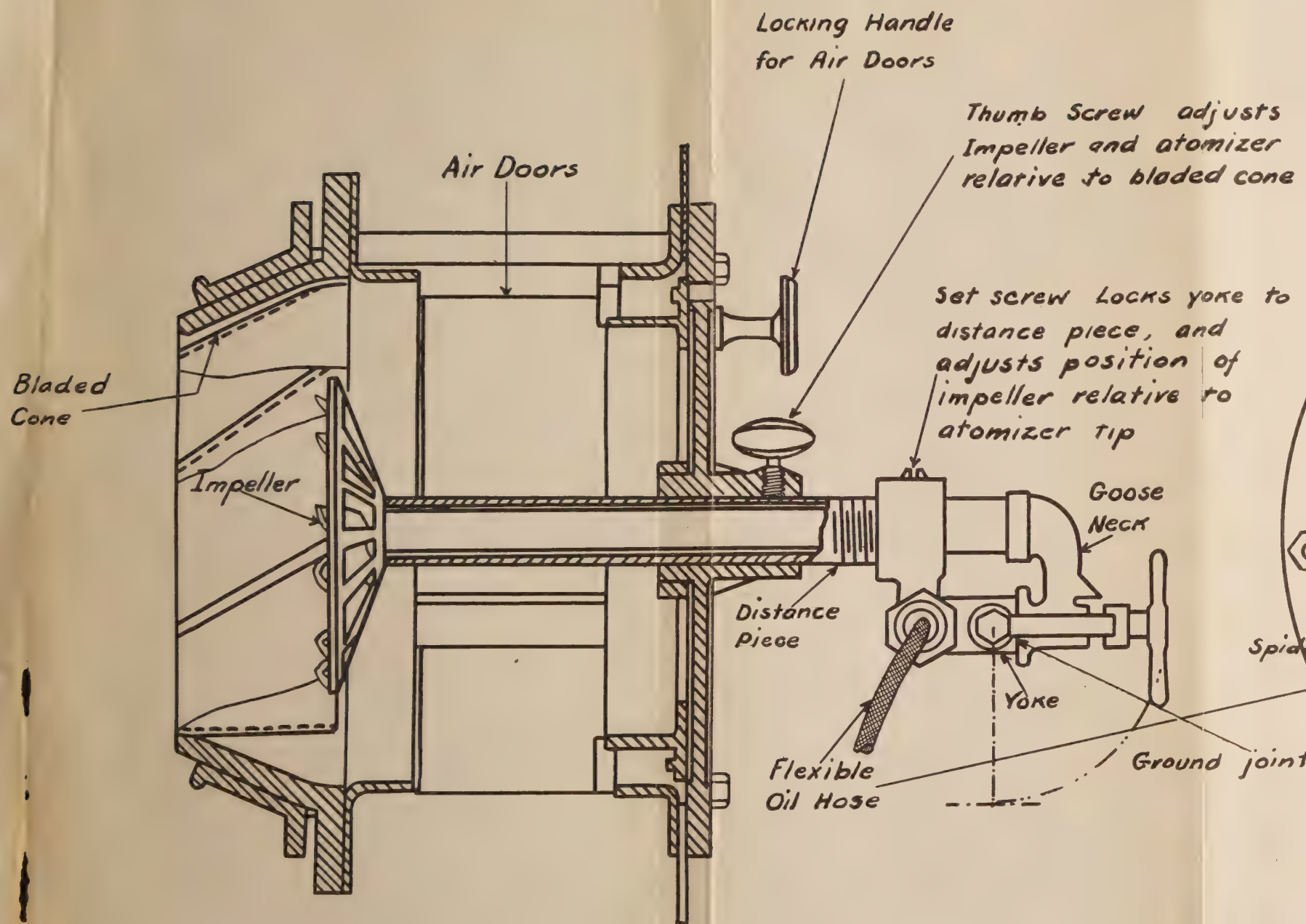
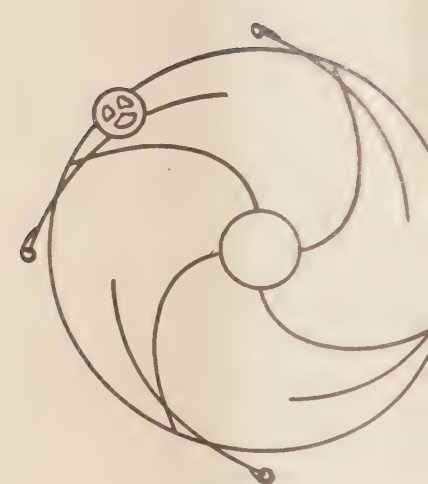


FIG. IV-7.—Mechanical Oil Atomizer. Cuyama Type.



Doors closed



Doors Open

Showing Action of Spider

PLATE IV-5.—Assembly of Cuyama Mechanical Oil Burner.

shaped opening to the furnace so that each particle of oil sprayed by the atomizer will be surrounded by air moving with high velocity.

(2) To a certain extent controls the amount of the air entering the furnace. When all registers are closed, no air enters the furnace.

(3) To a certain extent controls the velocity of the air entering the furnace.

Air registers may be *conical* or *cylindrical* in shape but the opening into the furnace is always cone shaped and faced with special fire brick called *cone brick*.

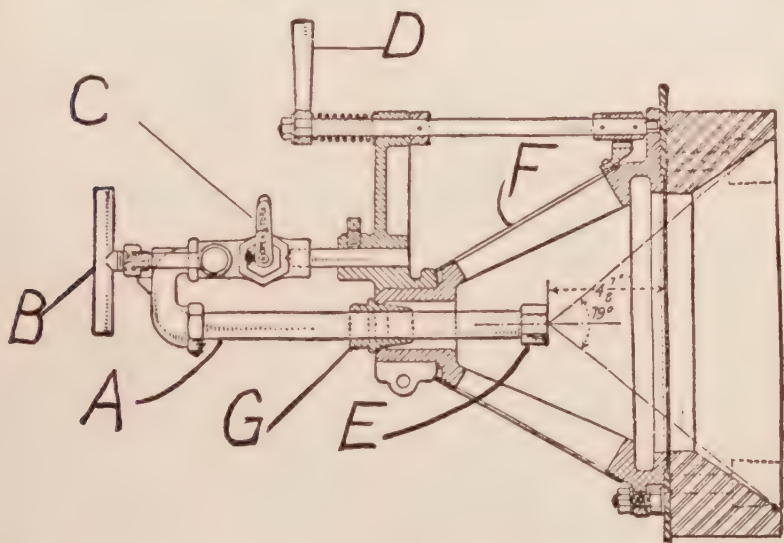


FIG. IV-8—Forced-draft air control register, Bureau of Engineering type. *A*, atomizer pipe; *B*, clamping screw; *C*, atomizer valve—controls the oil to the burner; *D*, hand lever for operating the air register; *E*, atomizer plug; *F*, air register; *G*, adapter for holding burner in place.

Bureau air register.—A conical type air register is made in the shape of the frustrum of a cone with slots down the side of the cone of such cross section as to give the air a rotary motion. Shutters adjusted by a lever regulate the quantity and velocity of the air entering the slots. A good example of the cone type air register is the Bureau of Engineering Type. (See Fig. IV-8.)

Cuyama air register.—The "Cuyama" and "Lodi" types of air registers are cylindrical in shape. Plate IV-5 shows the construction of the "Cuyama" type air register. The "Lodi" type is of similar construction but is of larger capacity.

As shown in Plate IV-5 the Cuyama type air register consists of the following parts: (1) a cast-iron grid supporting the cone brick. (2) A cast-iron bladed cone fitted with a slotted impeller plate to give the air a whirling motion. (3) A cylindrical-shaped cast-iron barrel, bolted to the inner and outer boiler casings, and fitted with sheet steel shutters. The amount of opening of these shutters is adjusted by a hand lever which can be locked in any position. The shutters are fitted with springs which allow them to close whenever a flare back or large steam leak creates an excessive pressure in the furnace.

The *atomizer* is inserted through the middle of the air register. The oil valve and gooseneck connection for connecting the atomizer to the fuel oil line are supported by the barrel of the air register.

The Bureau of Engineering natural forced-draft air register, Plate IV-6, is cylindrical in shape. The air is given a whirling motion by the curved shape of the slots in the cylindrical barrel of the register. The amount of air and velocity of the air is controlled by the position of a disc which may be moved in or out by a pinion operated by a handle. The cone-shaped stream of air is obtained by a cone-shaped diffuser which screws on to the end of the diffuser pipe.

The position of the diffuser in relation to the atomizer tip is fixed by the hand screw. The atomizer with the diffuser pipe locked to it may be moved in and out when the thumb screw is loosened. When the proper position of the diffuser and atomizer has been obtained, the thumb screw is set up. The "Natural Forced-Draft Air Register" was designed for use with either natural draft or forced draft, natural draft being used in port only. *The Manual of Engineering Instructions* now prohibits the use of natural draft except on ships which have no equipment for forced draft and then only when the installation has been approved by the Bureau.

Burners.—In general the term "burner" is applied to the apparatus on the boiler front which delivers the oil in a fine spray to the furnace and also delivers the air in such a manner as to mix with and surround the oil particles so as to give good combustion. The *burner*, therefore, includes the atomizer, the air register, and the necessary valves and fittings to connect the atomizer to the fuel oil line.

The types of burners in general use in the Navy are:

- (1) Bureau of Engineering Type 1 Burner which includes the Bureau of Engineering Type 1 air register (cone-shaped) and the Bureau of Engineering atomizer.
- (2) The Cuyama Burner which includes the Cuyama type air register and the Peabody atomizer.



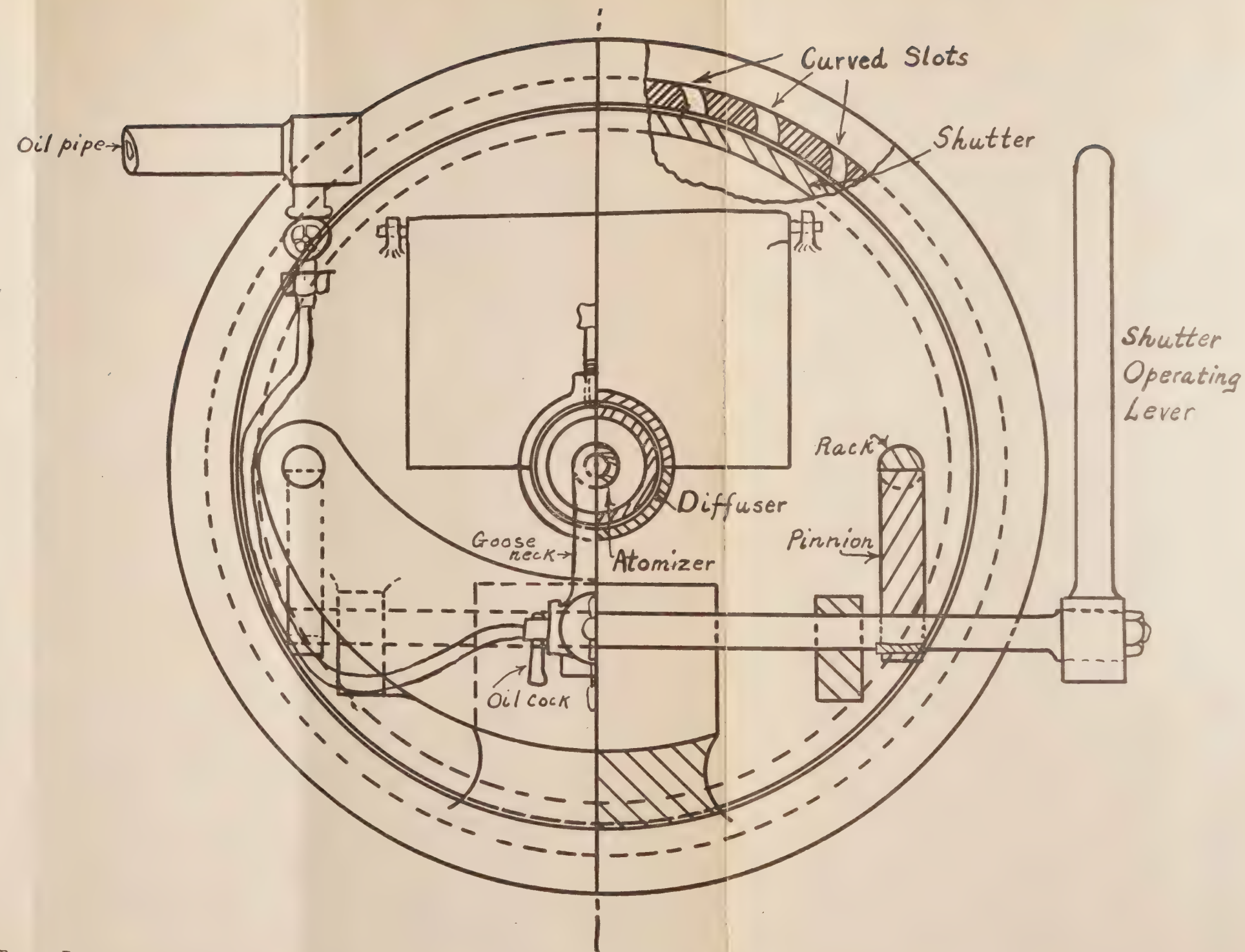
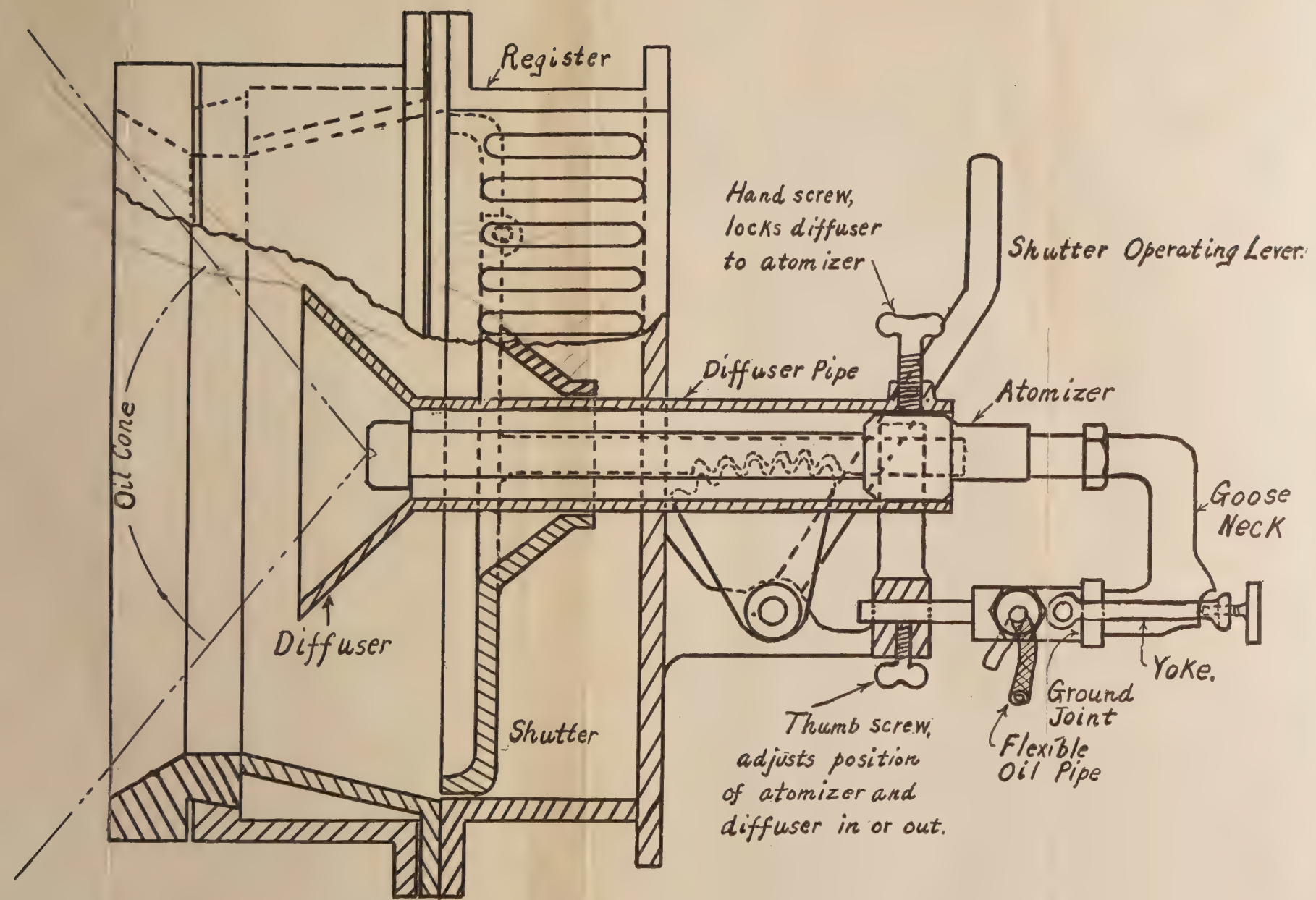


PLATE IV-6.—Natural Forced Draft Burner. Bureau of Engineering Type 1.

- 3) The Lodi Burner has the Lodi air register, which is similar to the Cuyama but larger, and the large-sized Peabody atomizer.
- 4) The Bureau of Engineering Natural Forced-Draft Burner which includes the Natural Forced-Draft air register and the Bureau of Engineering atomizer.
- 5) The Bureau of Engineering Type Blower Burner which includes a cylindrical air register, a small self contained propeller fan driven by an electric motor or a small steam turbine, and a small sized Peabody atomizer.

The Blower Burner is frequently called the "Mayflower" burner. It is intended for use in port or underway under low power and has been installed on a few ships. It has not been entirely successful and will not be described here.

The fittings by which the atomizers are secured in the various types of burners are standardized so that Peabody atomizers could be used in Bureau of Engineering types of burners and the Bureau of Engineering atomizers could be used in the Cuyama and Lodi type burners.

Smoke telegraphs.—An electrically operated signal system is installed on most oil burning men-of-war to signal the smoke conditions from the bridge or from other stations above decks to the firerooms. The transmitters and receivers show signals such as: "heavy black," "light black," "clear," "light white," "heavy white," "stop smoke," and "make smoke."

Burner control outfit.—The burner control outfit is an electrically operated signal system to signal the firerooms from the control station (usually in an engine room) to each boiler room, giving the following orders: number of burners to be used per boiler, oil pressure to be maintained, size of atomizer tips, etc. The usual procedure is to have the same oil pressure and same number of burners in use on all boilers, and to handle small fluctuations in the demand for steam by increasing or decreasing the number of burners in use on one boiler or on the boilers of one fireroom.

4. TESTING ACCESSORIES

Manometers.—A manometer or draft gage is installed in each fireroom to measure the difference between the pressure of the air in the fireroom and the pressure of the air at the top of the stack. This difference in pressure is called the draft and is usually given in inches of water. The type of manometer that is usually installed on board ship is a U-shaped tube of glass with one leg connected by a pipe to the atmosphere above the stacks, and the other leg connected to the air in the fireroom. The tube is

filled with water, colored red or blue. Scales graduated in inches are placed alongside each leg of the tube. The draft is the difference in height of the two tubes, read in inches of water. One type of manometer has a sliding scale which can be moved so that the zero mark is level with the water in one leg and the height of the water in the other leg may be read to give the draft direct without any subtraction.

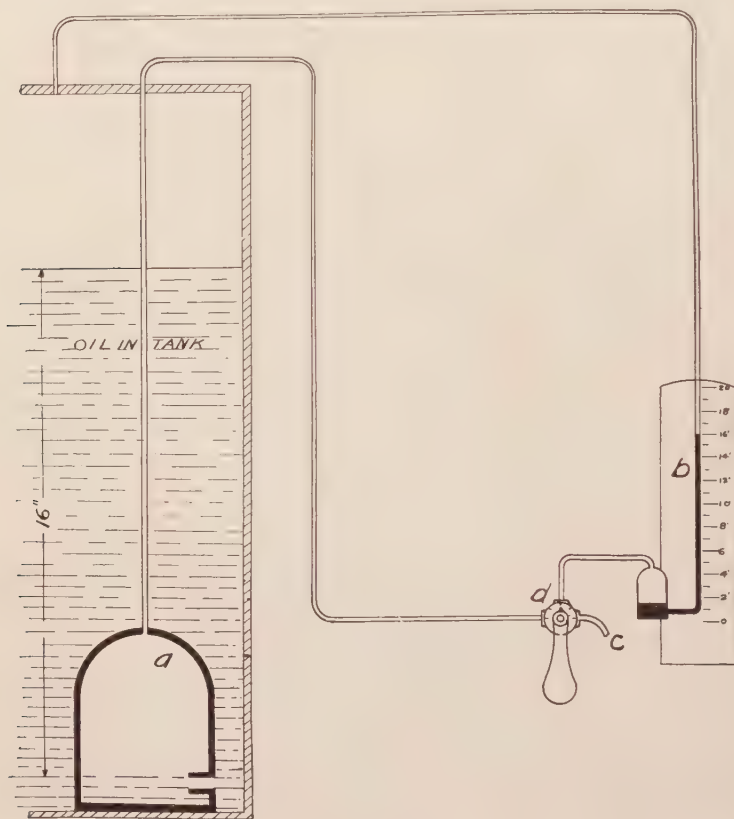


FIG. IV-9.

Note: A pressure of 1 inch of water at 15°C is equivalent to 0.073 inches of mercury at 0°C and to 0.036 lbs. per square inch.

Steam calorimeters.—The quality of the steam, i.e., the percentage of dry saturated steam in a unit weight of the steam, is measured by an instrument called a calorimeter. Calorimeters are not included in standard ship installations, but may be installed for experimental purposes.

Thermometers.—The temperatures of feed water, fuel oil, etc., are measured by thermometers.

Pyrometers.—A pyrometer is an instrument for reading fire temperatures, as in taking smoke pipe and furnace temperatures. Pyrometers are not ordinarily installed on board ship, but may be installed for special tests and trials.

Gages.—Pressures of steam, water, oil, etc., are measured by gages of the Bourdon tube type.

Pneumercators.—The pneumercator is an instrument for measuring the volume or weight of a liquid in tanks or reservoirs. It does this by the pressure within a balance chamber located in the tank, the pressure being dependent upon the height of liquid above an orifice in the balance chamber and being communicated to a mercury column by a very small pipe line. The essential elements of the instrument are: (a) balance chamber; (b) a mercury gage calibrated in feet and inches in corresponding weights or volumes; (c) a pump or other means for supplying compressed air; and (d) a control valve (see Figs. IV-9 and IV-10).

The several positions of the control valve are: "Gage," "shut," "air," and "vent" (as indicated on the valve). At "gage," the balance chamber communicates with the gage; at "shut," all openings are closed; at "air," the balance chamber and the air pump are in communication; at "vent," the mercury column is cut off.

The installation and operation are as follows: The balance chamber is located in the tank so that its orifice is at a definite point near the tank bottom. The pipe is run to the locations where the readings are to be taken. When the tank is being filled, the control valve is placed at "gage," thus permitting the gage to indicate the rise of liquid. During the process of filling when accurate readings are desired the control valve should be turned to "air" so that the level of liquid within the chamber may be maintained at the orifice of the balance chamber, this level tending to rise above the orifice and to cause inaccurate readings by the gage. A few strokes of the pump are necessary for this purpose. The control valve is now turned to "gage," and accurate readings are assured. A pipe is installed connecting the top of the gage mercury column with the particular tank that the gage serves. This assures accurate readings in case either pressure or vacuum exists on the tank. A duplicate column is provided for each tank at the engine board to operate the annunciator, by low voltage electric current; this annunciator indicating "95 per cent full" and "low" levels.

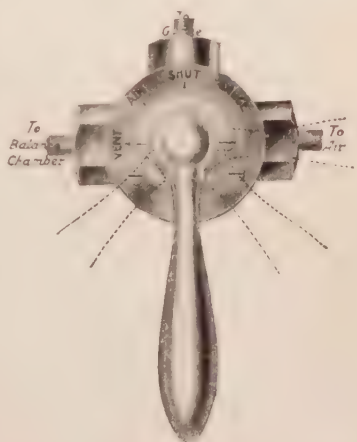


FIG. IV-10.—Pneumercator Control

CHAPTER V

COMBUSTION

Heat.—In accordance with the modern theory, heat may be defined as “energy stored in a substance by virtue of the state of its molecular action,” it is not a substance and must be a quality, and this quality can only be a motion.

Thermal energy.—Heat is usually spoken of as thermal energy, it may be either kinetic or potential in form. Thermal energy is measured by observing its effect upon a body.

Temperature.—The effect of molecular action is observed by the changes in temperature caused by the heat produced or absorbed. Temperature therefore may be regarded as an effect of molecular action. If the velocity of a molecule be denoted by V and its mass by M , the kinetic energy of the molecule is $\frac{1}{2}MV^2$ and that of the mass of molecules under observation is $\frac{1}{2}MV^2 = MC^2$, where M is the mass under observation and C^2 is a function of the temperature. The temperature of the mass is a measure of its thermal kinetic energy. If a gas is heated without change in volume, the relative distances apart of the molecules remain the same, but the velocities of the molecules or the thermal kinetic energy increase. If a gas is heated and allowed to expand a portion of the thermal energy applied to the mass of gas is absorbed in separating the molecules—this energy is recoverable if the gas is brought in contact with a cooler body and is therefore potential energy. Temperature is measured in Fahrenheit or Centigrade units. Under standard conditions, the temperature of melting ice is 32° F. or 0° C. and water boils at 212° F. and 100° C. One degree range of Centigrade temperature = $\frac{9}{5}$ degree range of Fahrenheit temperature.

British thermal unit.—The quantity of heat required to raise the temperature of one pound of water 1° F. Since this quantity varies as the specific heat, the mean B. t. u. defined as $1/180$ of that quantity of heat consumed in raising one pound of water from 32° F. to 212° F. at atmospheric pressure, is generally used.

Thermal energy in boiler practice is measured in B. t. u.

In boiler-plant operation thermal energy is observed under two general heads:

- (1) Thermo-chemistry and
- (2) Thermo-dynamics

Thermo-chemistry. The evolutions or absorptions of heat accompanying atomic combinations and molecular decompositions are the subjects of the thermo chemistry. Boiler-plant thermo chemistry is mainly concerned with the atomic combinations and molecular decompositions which occur when hydrocarbon fuels are combined with oxygen in boiler furnaces.

Thermodynamics.—When heat has been released or generated in a boiler, the utilization of the heat thus made available is governed by certain considerations and laws which are within the scope of applied engineering thermodynamics. The expression thermodynamics is defined as the science of energy. The application of the heat generated by thermo-chemical action in the furnace to the contained water in the boiler is governed by certain thermodynamical considerations, elementary in their nature, which are preliminary to the study of applied thermodynamics, which the midshipmen take up later in the engineering course.

Thermo-chemistry in the boiler plant.

Combustion. The evolution of heat which accompanies the chemical union of hydrocarbons with oxygen is termed combustion.

Combustible substance. A combustible substance is one which, when raised to its temperature of ignition, combines readily with the oxygen in the air, producing heat. The combustible substances which, at present, are applied for naval boiler fuel purposes are:

- (1) Coal.
- (2) Petroleum.

The five principal elements found in coal and petroleum are:

<i>Element</i>	<i>Symbol</i>	<i>Approximate Atomic Weight</i>
Carbon	C	12
Hydrogen	H	1
Oxygen	O	16
Nitrogen	N	14
Sulphur	S	32 —

The two principal elements found in the air are:

Oxygen 23 per cent by weight, 21 per cent by volume.
 Nitrogen 77 per cent by weight, 79 per cent by volume.

The *atomic weights* are the relative proportions, by *weight*, in which the elements combine with each other to form definite chemical compounds thus: $2\text{H} + \text{O} = \text{H}_2\text{O}$ or 2 lbs. H + 16 lbs. O = 18 lbs. H_2O (water). Similarly, 12 lbs. C + 16 lbs. O = 28 lbs. CO (Carbon monoxide).

12 lbs. C + 32 lbs. O = 44 lbs. CO_2 (Carbon dioxide).

The inorganic chemistry involved has been studied by the midshipmen prior to proceeding with the study of the boilers and will not be elaborated except as may be necessary to clarify the thermal processes encountered.

When the elements H, C, and S combine thermo-chemically with oxygen the thermal energy or B.t.u.'s, resulting from the process of combustion per pound of element have been accurately determined for ideal conditions as follows:

One pound hydrogen, burned to liquid water (H_2O) generates (a) 62,032 B.t.u.'s. (b) 61,816 B.t.u.'s.

One pound Carbon, burned to CO_2 generates 14,647 B.t.u.'s.

One pound Carbon, burned to CO generates 4,451 B.t.u.'s.

One pound Sulphur, burned to SO_2 generates 4,050 B.t.u.'s.

Note that hydrogen has a low and a high heating value.

Determination of heating values of a fuel.

Heating values.—The heating value of a fuel is determined from the heating values of the several constituents after the ultimate or chemical analysis of the fuel (a laboratory process) has disclosed the proportionate relations of the constituents.

Example H-1. Required: The heating value of a coal, given the percentages of the constituents.

Constituents by ultimate analysis.	Percentage per unit weight	Weight in lbs. per lb. of coal	Heating value per unit wt.	Total heating values.
H_2	4.84	0.0484	62,032	3,002.35
C	78.78	0.7878	14,544	11,457.76
N	1.07	Non-combustible		
O	7.64	Neglected in this example.		
S	0.66	0.0066	4,050	26.73
Ash	7.01	Non-combustible		

Total B. t. u. per lb. of coal 14,486.84

Example H-2. Required: the heating value of a petroleum, given the percentages of the constituents.

Constituents by ultimate analysis.	Percentage per unit weight	Weight in lbs. per lb. of petroleum	Heating value per unit wt.	Total heating values
H ₂	13.0	0.13	62,032	8,064.16
C	85.0	0.85	14,544	12,362.40
O	1.0	Neglected in this example		
N	0.2	Non-com- bustible		
S	0.8	0.008	4,050	32.40
Water	1.0	Neglected		

Total B. t. u. per lb. of petroleum 20,458.96

Examples H-1 and H-2 neglect the oxygen constituents.

It is more accurate to assume that the oxygen in the fuel has combined with its combining weight of hydrogen and the heat so generated lost. A formula has been devised in which the term $(H - \%)$ is used to reduce the heating value for the oxygen constituent.

Dulong's formula. Dulong's formula is expressed:

$$\text{Heat value in B. t. u.} = \frac{1}{100} [14,600 C + 62,000 (H - \%)].$$

When C, H, and O are the percentages by weight of carbon, hydrogen, and oxygen in the fuel as determined by analysis. Using Dulong's formula:

Example H-1 gives:

$$\frac{1}{100} [14,600 \times 78.78 + 62,000 (4.84 - 7.91\%)] = 13,910.58 \text{ B. t. u.'s.}$$

Example H-2 gives:

$$\frac{1}{100} [14,600 \times 0.85 + 62,000 (13.0 - 1.0\%)] = 20,392.50 \text{ B. t. u.'s.}$$

Inchley's formula. For petroleum and empirical formula based on the ultimate analysis known as M. Inchley's empirical formula is generally used. This formula is stated:

$$\text{B. t. u. per pound of petroleum} = 13,500 C + 60,890 H$$

Using M. Inchley's formula:

Example H-2 gives

$$13,500 \times 0.85 + 60,890 \times 0.13 = 19,390.70 \text{ B.t.u.'s.}$$

Note: Laboratory reports of the heating values of fuels will be found in chapter X.

Air required for combustion.—Having determined the heating value of a fuel the next problem in boiler thermo-chemistry is to calculate the amount of air required per unit weight of fuel to support complete combustion. The oxygen of the air combines with the hydrocarbons of the fuel under the influence of heat in the furnace of a boiler.

Under average conditions 1 pound of air has mixed in it 0.23 pounds of oxygen.

Reductions resulting from combustion:—

(a) C to CO_2 ,

$\text{C} + 20 = \text{CO}_2$ whence using the atomic weights

12 lbs. C + 32 lbs. O = 44 lbs. CO_2 .

$\therefore$ 1 lb of C requires 2.667 lbs. of O for reduction to CO_2 .

(b) H to H_2O ,

$2\text{H} + \text{O} = \text{H}_2\text{O}$ whence using the atomic weights.

2 lbs. H + 16 lbs. O = 18 lbs. H_2O

$\therefore$ 1 lb. of H requires 8 lbs. of O. for reduction to H_2O .

(c) S to SO_2 ,

$\text{S} + 20 = \text{SO}_2$ whence by using the atomic weights.

32 lbs. S + 32 lbs. O = 64 lbs. SO_2 .

$\therefore$ 1 lb. of S requires 1 lb. of O for reduction to SO_2 .

Referring to the coal of example H-1, the weight of the air required for reduction is calculated thus:

Constituent	Wt. per lb. of coal	Lbs. of oxygen required per unit weight of constituent	Total oxygen in lbs.
H_2	0.0484	8	0.3872
C	0.7878	2.667	2.1011
S	0.0066	1	0.0066
			Total O = 2.4949 lbs.

$$\text{The air required} = \frac{2.4949}{0.23} = 10.848 \text{ lb. of air per lb. of coal.}$$

Referring to the petroleum of example H-2, the weight of the air required for reduction is calculated:

Constituent	Weight per lb. of petroleum	Lbs. of oxygen required per unit weight of constituent	Total oxygen in pounds
H_2	0.13	8	1.040
C	0.85	2.667	2.267
S	0.008	1	0.008
			Total O = 3.315 lbs.

$$\text{The air required} = \frac{3.315}{0.23} = 14.413 \text{ lbs. of air per lb. of petroleum.}$$

The air required to burn one pound of coal or one pound of petroleum in actual practice exceeds the theoretical solutions from 20 to 25 per cent; 13 to 13.5 pounds of air per pound of coal and 17 to 18 pounds of air per pound of petroleum, more nearly represent the quantities of air required under actual operating conditions.

The supply of air for combustion, and the ejection of the burned gases, requires a practical application of the laws of physics applicable to gases. The weight of one cubic foot of air at normal sea level barometric pressure of 14.7 pounds and a temperature of 32° F. is assumed to be 0.08007 pounds and conversely the volume of one pound of air under the same conditions is 12.387 cubic feet.

The weight of air at a given pressure is inversely proportional to its absolute temperature.

Air is supplied to the fireroom by creating a draft.

Draft.—Draft is the flow of gases through the air registers (fire bed), furnace, gas passages, and smoke pipe. The flow is caused by differences in pressure between the supply of air to the fireroom (air at atmospheric pressure outside the ship), and the exhaust from the stack (the gases of combustion). Draft may be either natural or forced.

Natural draft.—Where the flow of gases takes place without mechanical assistance the draft is termed “natural draft.”

Forced draft.—When the flow of gases due to natural causes is insufficient to support the rate of combustion desired, mechanical assistance is applied and the draft is termed “forced.”

Calculation of “natural draft.”

Example H-3. The top of a smoke pipe is seventy two feet above the air registers, the temperature of the gases in the smoke pipe is 540° F., the temperature of the air outside is 72° F. Calculate the draft.

$$\text{Outside air weighs } 0.0807 \times \frac{(460^\circ + 32^\circ)}{(460^\circ + 72^\circ)} = 0.0746 \text{ lbs. per cu. ft.}$$

$$\text{Stack gases weigh } 0.0807 \times \frac{(460^\circ + 32^\circ)}{(460^\circ + 540^\circ)} = 0.0396 \text{ lb. per cu. ft.}$$

The pressure of the outside air on a plane at the mean level of the air registers is $72' \times 0.0746 = 5.3712$ lbs. per sq. ft.

The pressure of the stack gases (assumed for the purpose of this problem to rise from the mean level of the air registers) is $72' \times 0.0396 = 2.8512$ lbs. per sq. ft.

The difference in pressure $5.3712 - 2.8512 = 2.5200$ lbs. per sq. ft., is the flow of gas pressure or draft.

Draft is usually measured in inches of water. $2.52 \text{ lbs. per sq. ft.} = 2.52 \div 144 = 0.0175 \text{ lbs. per sq. in.}$ Assume 1 cubic foot of fresh water

weighs 62.4 pounds, then a column of one inch in height and of one square inch cross-sectional area weighs 0.0361 pound and the draft is thence expressed as

$$\frac{0.0175''}{0.0361''} = 0.485'' \text{ of water.}$$

The calculation of draft in this manner is approximate only. The flow of the gas stream through the boiler plant is subject to variations in temperature and pressure caused by the conditions in the furnace, restrictions due to variations in the area of the gas passages and to variations in the quality of the fuel.

Rankine's formula.—Rankine has deduced a formula in which certain corrections for conditions usually encountered in draft problems are taken into consideration.

Rankine's formula is expressed thus:

$$h = \frac{0.0807 (T_o/T_a)}{0.084 (T_o/T_s)} \times H - H = [0.06 (T_s/T_a) - 1] \times H$$

h = the height of a column of hot gases, which if added to the column of gas in the stack would produce the same pressure at the furnace as a column of outside air of the same area of base and of the same height as the stack.

H = height of stack.

$T_o = 492^\circ \text{ F.} = (t + 460) = (32 + 460).$

T_s = absolute temperature of gases in the stack in degrees F.

T_a = absolute temperature of the outside air in degrees F.

Solving example H-3 with Rankine's formula:

$$h = \left[0.96 \frac{(460+540)}{460+72} - 1 \right] \times 72 = 63.34 \text{ ft.}$$

$$63.34 \times 0.0396 = 2.51 \text{ lbs. per sq. ft.}$$

$$\frac{2.51}{144 \times .0361} = 0.483'' \text{ of water.}$$

Kent's formula is expressed thus:

$$F = H \left[\frac{7.64}{T_a} - \frac{7.95}{T_s} \right]$$

In which F is the force or intensity of draft, expressed in inches of water.

Solving example H-3 with Kent's formula:

$$F = 72 \left[\frac{7.64}{532} - \frac{7.95}{1000} \right] = 0.462'' \text{ of water.}$$

If the draft of example H-3 is sufficient to support the combustion of 4 pounds of fuel oil per cu. ft. of furnace volume per hour (oil of example

(1-2), the air that must enter the furnace for each cu. ft. of furnace volume

$$4 \times \frac{14.413}{.0746} \times \frac{1}{60} = 12.88 \text{ cu. ft. per minute.}$$

A common ratio of stack cross sectional area to furnace volume is one to twenty eight. Assuming this ratio, 360.6 cu. ft. of gas must pass up the stack per minute per sq. ft. of cross-sectional area.

Velocity of stack gases.—The velocity of the stack gases may be computed as follows:

Let H = height of stack above the grate—in ft.

A = cross-sectional area of stack—in sq. ft.

T_s = absolute temperature of stack gases—in degrees F.

T_a = absolute temperature of air supply—in degrees F.

U = velocity of gases inside stack—in ft. per sec.

W_g = weight of gases passing through stack—in lbs. per sec.

W_s = weight of 1 cu. ft. of stack gases—in lbs.

W = weight of 1 cu. ft. of air supply—in lbs.

P = pressure of atmosphere at top of stack—in lbs. per one sq. ft.

When the weight of the gases inside the stack = $A.H.W_s$

Pressure outside stack at grate level = $P + A.H.W_g$

Pressure inside stack at grate level = $P + A.H.W_s$

Difference of pressure outside and inside when gases are not in motion = $A.H.(W_g - W_s)$.

In practice, however, the gases are in motion upward, and the force pro-

ducing motion $M.U = \frac{W}{g} \times U = A.H.(W_g - W_s)$ in which $W = U.A.W_s$

$$\therefore \frac{U^2}{g} A = A.H.(W_g - W_s)$$

$$U = \frac{492 \times 0.0807}{t_o} \text{ and } u = \frac{492 \times 0.0807}{T_o} \text{ (From Boyle's and Charles' law)}$$

$$V = K.T_o \text{ and } \frac{W_g - W_s}{W_s} = \frac{T_o - t_o}{T_o} \text{ Whence } U = \sqrt{\frac{T_o - t_o}{t_o} \cdot g \cdot H.}$$

This deduction of U is of practical application in cases where it is desired to ascertain blower speeds, or the mechanical assistance necessary to produce the draft required.

Returning to the example: If the rate of combustion is increased to 16 lbs. per cu. ft. of furnace volume per hour, four times the quantity of air must pass up the stack or $4 \times 360.6 \text{ cu. ft.} = 1442.4 \text{ cu. ft. per min.}$ The additional draft required will be:

$$\frac{1442.4 - 360.6}{360.6} \times .485 = 1.455 \text{ (by computation)}$$

$$\times .483 = 1.43 \text{ (by Rankine's formula)}$$

$$\times .462 = 1.375 \text{ (by Kent's formula)}$$

The officer-in-charge of the boiler division can translate the draft indicated by the draft gages into blower outputs (cu. ft. of air per minute) blower speeds, or blower powers (steam or electric power consumption). If the speeds of the blowers do not give the draft desired, it is imperative that a search be instituted at once to determine the cause.

Losses due to insufficient draft.—One pound of the fuel oil in example H-1 burned under ideal conditions causing a complete reduction of the carbon to CO_2 requires $\frac{2.267}{.23} = 9.856$ lbs. of air per pound of fuel for the reduction of the carbon to CO_2 , thus when burning 16 lbs of fuel oil per cu. ft. of furnace volume per hour $= 1442.4 \times \frac{9.856}{14.413} = 993.5$ cu. ft. required for the combustion of the CO_2 alone. But, since hydrogen combines readily and burns, any deficiency of air will lead to incomplete combustion of the carbon causing the formation of CO instead of CO_2 .

Assume that only 900 cu. ft. of air are supplied, a deficiency of 93.5 cu. ft. This shortage will result in the loss of B.t.u.'s. as follows (temperature changes not considered) :

Air supply below 9.85 lbs. per lb. C = 9.4%

Lbs. air per lb. of carbon = $9.85 \times .906 = 8.94$

Air plus gas = gas lbs. = 9.94

C burned to $\text{CO}_2\%$ = 81.2

C burned to CO% = 18.8

B.t.u. generated or making $\text{CO}_2 = 11,893.4 \text{ } (.812 \times 14,647)$

CO = 836.8 $(.188 \times 4,451)$

Total heat generated = 12,730.2

Loss due to incomplete combustion = 14,647

12,730.2

1,916.8 B.t.u.'s.

Expressed as a per cent efficiency of fuel consumption this becomes 86.9 per cent.

Fuel losses due to incomplete combustion causing the formation of CO in place of CO_2 are investigated by means of gas analysis equipment, one of which is described later in this text. Corresponding temperatures of

furnaces, gas passages, uptakes and stacks are obtained by means of thermometers.

Temperature effects due to an excess air supply. The rise in temperature corresponding to 20,458.9 B.t.u. per lb. of fuel oil with a supply

$$\text{of } 14.413 \text{ lbs. of air of specific heat } 0.24 = \frac{20,458.9}{14.413 \times .24} = 5,917 \text{ } ^\circ\text{F.}$$

If the supply of air be increased to 20 lbs. per pound of fuel oil per hour, the rise in temperature becomes $\frac{20,458.9}{20 \times .24} = 4,268^\circ \text{F.}$

This means that a large loss is occurring in heating the excess air, such a condition is frequently encountered in "smokeless runs." Where the zeal to avoid smoking causes the personnel to supply an excess of air.

The thermal energy released by the thermo-chemical process of combustion in the furnace is observable so long as a difference in temperature between the source and the surrounding objects exists. Differences in temperature cause heat transfer. Heat transfer takes place in three ways:

(1) By radiation, (2) by conduction, (3) by convection.

Radiation.—Heat transfer between bodies separated an appreciable distance occurs in accordance with the laws for the radiation of light. Heat rays proceed in straight lines from the source and the intensity of the heat from the rays radiated from the source varies inversely as the square of this distance from the source.

The heat of the rays from the source is called "radiant heat" and must not be confused with the heat which is conveyed by means of an intervening body such as air or metal, which is convected heat. The air surrounding boiler casing serves as a convection medium to convey away heat passing through the casing.

Radiant heat is absorbed or transferred more readily by dark and rough bodies and conversely bright surfaces reflect radiant heat readily. Incandescent brickwork in furnace readily reflects radiant heat. This radiant heat, reflected upon the water containers, aids other modes of heat transfer. Stefan and Boltzman's law states that the energy radiated by a black body is proportional to the fourth power of the absolute temperature or $E = K (T^4 - T_0^4)$, where E = total energy radiated by a body at T to the body at T_0 and K is a constant.

The total radiation from other than black bodies increases more rapidly in the fourth power of the absolute temperature, so that as the temperature is raised the radiation of all bodies approaches that of a black body.

Conduction.—Heat transfer between like or dissimilar bodies, which are in contact, takes place by conduction where no appreciable current or flow of molecules occurs due to the passage of heat. The rate of heat

transfer by conduction depends upon the thermal conductivities of substances. Some conductivities are:

Steel 279.5 B.t.u. per hour per sq. ft. at 82° F.

Water 3.6 B.t.u. per degree F. per inch thick at 65° F.

Air 0.165 B.t.u. per degree F. per inch thick at 32° F.

CO₂ 0.144 B.t.u. per degree F. per inch thick at 212° F.

The thermal conductivity for any gas is very much lower than that of any solid and this fact has an extremely important bearing on the design of heating surfaces to obtain maximum heat transfer.

The resistances of gases to transfer of heat by conduction when not in motion has an insulating effect. This property is extensively employed in the use of air cells to reduce conduction of heat. Air spaces are provided between inner and outer casings of boilers; for this reason the effectiveness of such insulation depends upon the degree of stagnation of the air in the spaces. Openings in the casings produce air currents with consequent losses.

Convection.—When gases or fluids are in motion, the heat transfer is greatly accelerated, the particles nearest the sources of heat flow through the mass of the gas or liquid toward a region of less pressure and are replaced by colder particles until the entire mass is of uniform temperature or the molecular velocities have become equalized.

The flow of heat from the gases to the water takes place as follows:

(1) From source of heat to gas film adhering to water containers by convection.

(2) Through the gas film to metal of container by conduction.

(3) Through the metal by conduction.

(4) From metal to adhering water film by conduction.

(5) From water film to water by convection.

As the gas film which adheres to the water containers acts as an insulator; i.e., as a gas not in motion, its presence is accountable for a large proportion of the loss of heat from the hot gases.

This loss is reduced in part by directing the gas flow along tubes or containers instead of across them thus obtaining a gas scouring effect, the cohesion of the gas particles tending to keep the adhering film to the minimum thickness consistent with the condition of the surfaces over which the gas is flowing and the velocity of the gas flow.

The water film while not so large a factor in the heat losses is of such importance that the water circulation must be arranged so to reduce the water film to a minimum thickness.

The usual effect of soot, rust, and scale of deposits of insoluble substances acting according to their thermal conductivities is to hinder the

heat transfer. When this hindrance takes place between the metal of the water container and the water film the molecular velocities in the metal of the container may produce temperatures of flow of the metal and cause rupture of the wall of the container. Likewise the replacement of the convection medium (water) with a gas (dry or superheated steam) causes similar effects.

When the water supply is stopped or is insufficient to produce an active flow on the water side the high resistance factor of a gas (steam) the result and to be expected effect is the rupture of the wall of the water container.

Forms of water.—Water is the liquid employed in marine boiler practice as a heat conveying medium. Under normal conditions of atmospheric pressure 14.7 lbs., and at a temperature of 32° F. and below, water is a solid. At 32° F. the atmospheric pressure upon the addition of heat changes from a solid state to a liquid state, about 143.6 B.t.u.'s. per pound are absorbed in changing from a solid to a liquid without change of temperature. If the pressure is maintained at one atmosphere, the temperature of the water may now be raised from 32° F. to 212° F. by the application of one B.t.u. per degree F. per pound of water. When a temperature of 212° F. is reached no further change in state or temperature will be noted until a quantity of heat known as the latent heat of steam has been applied. This quantity for a pressure of one standard atmosphere is about 970.4 B.t.u. per pound of water.

Boiling point.—The temperature at which water is converted into steam is known as the boiling point. This temperature varies with the pressure existing upon the surface of the water and with the purity of the water.

Under atmospheric pressure sea water, for example, requires about 1.2° additional rise in temperature for each 1/32 part of solid matter, above 212° F. The steam formed at the higher temperatures however is identical with steam formed from pure water at the same temperature and pressure. The heat absorbed by the solid matter serves no useful purpose.

Sensible heat.—The quantity of heat in B.t.u.'s. which when added to the body causes a change in temperature but not in state is called sensible heat.

Specific heat.—The quantity of heat required to raise one pound of substance 1° F. under given external conditions is known as the thermal capacity of the substance for these conditions. The mean thermal capacity of a body at some given temperature, compared with the mean thermal capacity of an equal weight of water at some standard temperature, known as the specific heat of a body.

Latent heat.—The quantity of heat which if applied to a liquid produces a change of state without rise in temperature or change in pressure is called the latent heat of the liquid. Latent heat in the case of steam consists of two parts:

(1) *Internal latent heat.* That heat required to overcome the molecular attraction of the molecules of the water in resisting a change of state.

(2) *External latent heat.* That heat equivalent to the work done in changing the volume at constant pressure during the change of state from water to steam.

An expression for external latent heat:

$$\text{External latent heat in B.t.u.'s.} = \frac{P}{J} (v - v_w)$$

Where P = absolute pressure in pounds per sq. ft.

v = specific volume of saturated steam.

v_w = volume of 1 lb. of water.

J = Joule's equivalent, 778 ft. lbs. = 1 B.t.u.

Latent heat of steam is potential thermal energy available for transformation into mechanical energy.

Total heat of steam.—From the preceding text it is evident that the total heat of steam (above 32° F.) includes three elements:

(1) The heat required to raise the temperature of water to the temperature of steam at any given pressure.

(2) The heat required to evaporate the water at that temperature and pressure is called internal latent heat.

(3) The latent heat of volume, or the external work done by the steam in making room for itself against the pressure of the superincumbent atmosphere (or surrounding steam if enclosed in a vessel).

Example H-5. Find the total heat required to generate 1 lb. of steam at atmospheric pressure (14.7 lbs.) and a temperature of 212° F. from water at 72° F. (From Steam Tables).

Sensible heat, to raise water from 72° F. to 212° F. = 140 B.t.u.

Latent heat (1) of the formation of steam at 212° F. (internal) = 898.8 B.t.u.

(2) of the expansion against atmospheric pressure = 14.7×144 lbs. per sq. ft. $\times (2,681 - 0.017)$ cu. ft. $\div$ (external work done) = 72.8.

Total B.t.u. = 1,110.4.

To obtain the total heat of steam at various pressures, consult Table I "Properties of saturated steam."

Example H-6. Required the total heat of 1 lb. of steam at 265.3 lbs. pressure per gage — barometer 14.7 lbs. Gage + barometer = 265.3 + 14.7 = 280 lbs. absolute.

In the table corresponding to 280 lbs. absolute pressure it will be noted that temperature is 411.2° F., the total heat above 32° F. is 1,203.1 B.t.u. and that the specific volume is 1.658 cu. ft. per pound.

Consulting Table I-C, it will be found that for saturated steam at 280 lbs., superheated 60°, has a total heat of 1,244.3 B.t.u. per pound and its specific volume is 1.84 cu. ft. per lb.

"Steam is *saturated* so long as it exists in the presence of water. It may be *wet and saturated*, in which case moisture, or water particles are carried along with it, or held in suspension. Wet saturated steam may be constituted of any proportions of water and steam. When steam is cleared of all water, either by complete evaporation, or by mechanical separation, and is not further heated, it is then *dry and saturated*. If the dry and saturated steam is heated further, it becomes superheated. Wet steam includes an infinite number of proportions of mixture of steam and water; superheated steam includes all degrees of superheating; but *dry saturated steam* means only one condition, viz., 100 per cent quality, 0 per cent moisture, and 0° superheat.

"For saturated steam, the pressure and temperature are definitely related. For example, at 100 lbs. absolute pressure, the temperature is always 327.8° F., no matter whether the quality is 50 per cent or 90 per cent, or 100 per cent. But as soon as the steam is freed of moisture, then its temperature can be raised without pressure by the addition of heat."

A modern naval boiler plant is designed to supply steam nearly or quite dry. However, a small quantity of moisture may be contained in the steam, this quantity rarely exceeds 1 per cent in good practice. The amount of moisture determines the relative dryness or *quality* of the steam. If the moisture content is 1 per cent the quality is 99 per cent.

To find the total heat of wet steam the following formula is used:

$$H = h + xL$$

Where H = total heat of wet steam, above 32°

h = the sensible heat or heat of the liquid above 32°

x = the quality of the steam

L = the latent heat of the steam

CHAPTER VI

FUELS

1. FUEL OIL

Liquid fuel.—The present day liquid fuel used in naval marine boilers of vessels of the first line is "petroleum." It, alone, of the various hydrocarbons, is available in sufficient quantity and distribution for general use as a fuel.

The supply of fuel oil for the mobile units of the fleet is one of the major problems confronting the Navy today. The rapid increase of the use of oil for civil purposes is draining the national resources very rapidly. The United States has reserved certain oil fields for ground reserves of oil fuel for naval purposes. Naval officers are concerned with the future supply of oil and the diplomatic situations arising consequent to the efforts of nations seeking reserves.

Crude petroleums are the result of processes of nature and are found in many localities. There are three theories held concerning the origin of crude oils, no one of which is universally accepted.

According to the *Inorganic Theory*, petroleum is produced deep down in the crust of the earth by the action of high temperature and pressure on the minerals found there; carbon and hydrogen are supposed to have combined and formed the hydrocarbons which are the chief constituents of crude petroleum. Only a minority of geologists favor this theory.

According to the *Vegetation Theory*, vegetable matter has been covered by a layer of impervious material; the air thus being excluded, rotting was prevented, and slow decay during hundreds of thousands of years transformed the vegetable matter into crude petroleum oil and petroleum gas. Several geologists favor this theory.

According to the *Marine Animal Theory* dead fish or tiny marine animals with calcareous shells were covered over by a layer of impervious material and their organic parts have gradually been transformed into crude oil and gas. Most geologists favor this theory.

Geologists generally agree that the world's supply of petroleum is practically complete and is being consumed rapidly.

Petroleum.—Crude petroleum gushes or is pumped from wells driven into the earth in favorable localities. When it comes to the surface it often contains water (frequently salt water) and sand, which are separated in large collecting and settling reservoirs. The crude oil is rarely transparent; the color is usually dark brown or black.

Crude petroleum consists chiefly of liquid hydrocarbons in which are dissolved both gaseous and solid hydrocarbons. The hydrocarbons are classed as follows:

Paraffines—of the general formula C_nH_{2n+2}

Olefines—of the general formula C_nH_{2n} (unsaturated)

Napthenes—of the general formula C_nH_{2n} (saturated)

Most crude petroleum is very complicated in character, and it is difficult to classify them; they contain hydrocarbons of practically all types, but the proportions vary considerably according to the origin of the petroleum.

The crude oils are referred to as *Paraffin Base Crudes*, *Asphaltic Base Crudes*, *Napthenic Crudes*, and *Mixed Base Crudes*.

Paraffin base crudes are so called because they contain paraffin hydrocarbons (C_nH_{2n+2}). The most important supplies of paraffin base crudes come from Pennsylvania and Ohio in the United States. They are fairly fluid, rich in gasolines and kerosenes, usually contain only a little asphalt, sulphur, oxygen, or nitrogen and have a low specific gravity.

Asphaltic base crudes are so called because they contain a large amount of asphalt. They usually contain certain small percentages of sulphur, oxygen and nitrogen. The crudes from California, Mexico, Texas, and South America belong to this class.

They are very viscous, black in color, rich in lubricating oils, fuel oils, and asphalt and have a high specific gravity; they often contain complex sulphur compounds which are difficult to extract.

The hydrocarbons in asphaltic base crudes are lower in hydrogen than the paraffins, although paraffins are often present. For example, California crudes contain olefines (C_nH_{2n}), asphaltic hydrocarbons (C_nH_{2n-4}), and also some benzenes (C_nH_{2n-6}). Texas crudes are rich in asphaltic hydrocarbons.

Napthenic crudes such as Russian crudes consist chiefly of napthenes (C_nH_{2n}); they also contain a small percentage of acetylene hydrocarbons (C_nH_{2n-2}). Russian crudes contain little or no paraffin wax.

Mixed base crudes are of a character intermediary between paraffin base crudes and asphaltic base crudes, containing both paraffin wax and asphalt. Mexican crudes are the most important mixed base crudes.

Fractional distillation.—For most purposes crude petroleum is refined before being used. The crude oil is run into large stills where heat is applied and a process known as fractional distillation is used to separate the hydrocarbons in the general order of their boiling points.

Among the products obtained in the distillation of petroleum are the following, named in the general order of their boiling points: Penetane,

hexane, the naphthas, kerosene, lubricating oils, vaseline, paraffin, and residue. The residue is either coke or a heavy viscous semisolid liquid of high boiling point hydrocarbons.

The oil which distills over after the light products, and before the lubricating stock, is of little value for further refining. It is generally known by the name "gas oil," as it is used to a considerable extent to give luminosity to illuminating gas.

"Gas oil" at the present time constitutes the high-grade fuel oil for Diesel engines. A mixture of "gas oil" with refinery refuse, such as the heavy asphaltic residues from the various distillations, goes to make up the different grades of fuel oils; the "gas oil" being used to reduce the viscosity of the heavy asphaltic residue.

Crude petroleum from the various fields differ in value for refining purposes. There are several different methods for carrying out this process. Some crudes contain a very small percentage of the more volatile oils. These oils are put in stills and heated until the limited amount of low boiling point hydrocarbons are distilled off. The residue is known as topped crude and is put on the market as fuel oil. Many of the Mexican and California oils are treated in this way.

Fuel oil.—A fuel oil for Navy use is generally a mixed oil made from the "gas oil" refinery refuse and the heavy residues obtained from distillations. They are mixed at the refinery in proper proportions to comply with Navy specifications for the various grades of fuel oils.

In the operation of an oil burning installation four characteristics of the fuel oil are of prime importance to the engineer, namely, the *flash point* of the oil, its *viscosity*, its *specific gravity*, and the *number of B.t.u's.* it contains.

Flash point.—The temperature at which an oil commences to give off a vapor that, when mixed with air, is inflammable, is known as the flash point. The two methods by which this point is determined are known as the "open-cup" and the "closed-cup" tests.

NOTE: See Chapter V, Bu. Eng. M.E.I., for description and operation of oil testing equipment.

The fire point or burning point is the temperature at which sufficient vapor is given off to remain ignited after flashing. As a free supply of oxygen is required, this test is made with the open cup.

The viscosity of an oil is the measure of the internal friction of the fluid or its resistance to flow. There are numerous methods by which viscosity is measured, and the observations in each case are recorded on an individual scale adopted to suit the instrument. With the majority of instruments it is generally stated as the time in seconds required for a given

quantity of the oil in question to flow through a small orifice at a stated temperature, or a ratio of the time of flow of the oil in question to the time of flow of water or some oil as a standard at a stated temperature.

In recording viscosity the name of the viscosimeter used must be given, also the temperature at which it was run. Absolute viscosity may be defined as the force in dynes required to move a layer of the liquid of one square centimeter area over another layer of the liquid with a velocity of one centimeter per second. It has not been found practical to actually measure viscosity by sliding plane surfaces over each other. The most accurate method developed is that of observing slow flow of the liquid through capillary tubes.

The absolute viscosity of water at 0° C. is 0.018086. If this were taken as the unit and the absolute viscosity of other liquids were expressed in these units, the result might be called "specific viscosity."

With the advent of the viscous crude oils of Mexico and the increased use of heavy distillates from other fields, coupled with the wide adoption of the mechanical atomizer or pressure burner, the degree of viscosity of oil becomes a matter of the utmost importance. Most viscous oil must be heated before pumping, and the viscosity must be reduced before it can be used in the burner; in fact, the whole problem of handling viscous oils really hinges on viscosity.

Determination of viscosity by capillary tubes is the most accurate method yet evolved; however, it is essentially a laboratory method. The apparatus involved is too delicate and complicated and the time required too long for commercial application.

Commercial viscosimeters.—In the commercial viscosimeters, such as the Engler, Redwood, and Saybolt, a small quantity of the liquid is permitted to flow through a cylindrical or conical opening that is short and relatively large in diameter, 0.5 to 0.75 inch long, approximately 0.01 inch diameter. The time of efflux of a given quantity is taken as indicating the viscosity.

The accuracy of the capillary tube is sacrificed to obtain ruggedness and commercial rapidity. Flow through short discharges is so rapid that turbulence and eddies with the lighter liquids cause nearly as much resistance as the actual viscosity of the fluid.

For identifying a liquid by comparison with a standard liquid the commercial viscosimeters are satisfactory, even though they may not indicate the true viscosity. For accurate study of the flow of liquids they cannot be relied upon.

Viscosity chart.—In order to supply the engineer officer with means for determining the viscosity of an oil at any temperature, a chart has been

developed wherein the coördinates are so arranged that the temperature viscosity relations when plotted appear as straight lines. (See Fig. VI-1.) If the viscosity of an oil is known at only one temperature and this point and the point "A" on the chart are used as coördinates, a straight line drawn through these points will show the viscosity of the oil at all other temperatures down to the "cloud test." The values taken from this chart are accurate for practical application.

The addition of a moveable pointer, of a translucent material to permit reading the chart underneath it, pivoted at point "A," upon which a line is engraved which passes through point "A," provides an instrument by means of which viscosity-temperature values may be taken out by inspection.

To illustrate, given a fuel oil whose viscosity is 100 seconds, Saybolt (Furol) at 50° F, what viscosity will the oil have at 130° F.? First establish line passing through point A and a point having the coördinates 50° F. and 100 seconds Saybolt (Furol). Then the ordinate corresponding to an abscissa of 130° F. is 16 seconds Saybolt (Furol).

For the same oil: to what temperature must the oil be heated to reduce it to a viscosity of 2° Engler? The point Δ on the viscosity curve has for its coördinates the given viscosity of 2° Engler and desired temperature. Reading from Fig. VI-1, $t = 160^{\circ}$ F.

NOTE: This chart, with the pointer and instructions complete, is issued to the service as Engineering Form No. 264. Bulletin of Engineering Information No. 22 of January, 1926, contains a full description of the theory of the chart, and describes a means of obtaining by experiment one viscosity-temperature determination for use with the chart.

The chart should be used on board ship for finding the temperature-viscosity relations of the oil in each tank or bottom. This should be done at each refueling or transfer of oil in order that proper temperatures may be used in heaters, for atomization, for pumping and for the recirculating systems.

It has been found that there is no curvature to the line for any mineral oil so far tested until the temperature has been reduced to the point where paraffin begins to precipitate, the temperature being that reported as the "cloud test" by the laboratory. Below this temperature viscosity rises so rapidly, due to greater precipitation of the paraffin, that the line becomes concave upward until it is vertical at a temperature reported by the laboratory as the "pour test." There is, of course, practically no paraffin in a well-refined naphthene or asphalt base oil, and accordingly there is no deviation from a straight line.

Fig. VI-1 supplies a ready means of converting viscosity readings from

FUEL OIL VISCOSITY - TEMPERATURE DIAGRAM

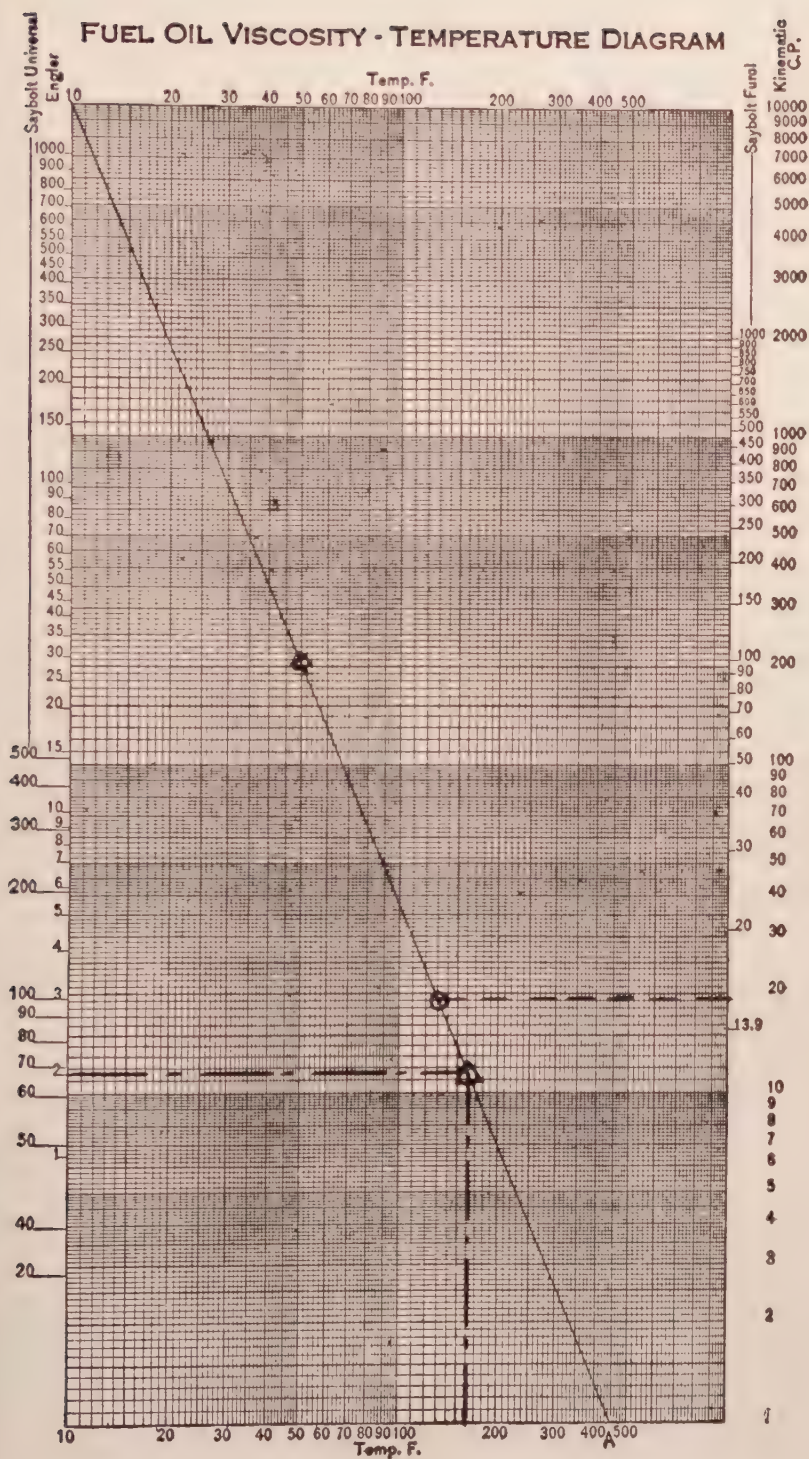


FIG. VI-1.

one standard system to another; i.e., Saybolt universal, Saybolt (Furol), Engler, and kinematic (centipoise).

The heat value per unit of weight is generally expressed in British thermal units (B.t.u.'s.) per pound of fuel. Since fuel is generally purchased by volume, and most engineering calculations are based on weight, it is well to remember that though a pound of the lighter grades of oils has a higher heat value than a pound of the heavy oils, a gallon of the former generally is lower in heat value than a gallon of the latter.

Density and specific gravity.—The *specific gravity* of fuel oil is the ratio of the mass of the fuel oil to the mass of an equal volume of water at some standard temperature. In engineering work, 60° F. is taken as standard.

The *density* of fuel oil is its mass per unit volume. The customary unit is in pounds per cubic foot.

The specific gravity of liquids is usually measured by means of a hydrometer. In handling liquid petroleum products, two arbitrary hydrometer scales are in general use, the A.P.I. (American Petroleum Institute) and the Baumé. The Baumé is the older scale but the A.P.I., having been approved by the American Petroleum Institute, U.S. Bureau of Mines, and the U.S. Bureau of Standards, is rapidly superseding the former. The relation between A.P.I. degrees and specific gravity is expressed by the following equation.

$$\text{Degrees A.P.I.} = \frac{141.5}{\text{Sp. gr. } 60^{\circ}/60^{\circ} \text{ F.}} - 131.5$$

" Baumé 140 - 130

In tabulations of specific gravity it is usual to show the temperatures, thus specific gravity at 60°/60° F. indicates the specific gravity of the oil at 60 degrees Fahrenheit is referred to water at 60 degrees Fahrenheit as unity.

Oil is sold in the United States by volume, not by weight. Therefore, the temperature at which it is measured must be given.

Tables VI-XVI in appendix, furnish ready methods of conversion of volumes and specific gravities at other than standard conditions to equivalent conditions at 60° F. These tables are based on the fact that within the limits of ordinary measurements the rate of change of specific gravity with a change of temperature is the same for all of the same specific gravity.

For example.—(1) One gallon of fuel oil measured at 98° having a specific gravity of 0.905 will have a specific gravity of 0.9184 at 60°/60° F. (Table VI). A specific gravity of 0.918 at 60°/60° F. corresponds to 22.57 degrees A.P.I. (Table VIII). Therefore a unit volume of 22.57 degrees

A.P.L. and 98° F. and 0.905 specific gravity will occupy 0.9848 gallons at 90° F. (Table XVI).

(2) A destroyer fuels from a tanker and receives 95,000 gals. sp. grav. Baumé, 20.2 at 40° F. For how many gallons at standard conditions will the engineer officer receipt? From Table XV, 20.2 Baumé equals 20.31 A.P.L. From Table XVI, the volume at 60° F. for oil of 20.31 A.P.L. at 40° F. is 1.00793. Therefore, engineer officer will receipt for

$$95,000 \times 1.00793 = 95,753$$

Specific heat of oil varies with its composition. It increases with an increase of hydrogen content and decreases with increase of carbon content. This specific heat is only of value to the engineer when he is desirous of calculating the required heating surface for coils in the tanks, etc.

Water and sediment in oil.—Though water is slightly soluble in oils, for practical purposes the engineer is only interested in the water present in mechanical suspension. Water and sediment are generally reported combined in percentage by volume, but it is much better to record them separately.

To determine the percentage of water and sediment in any oil, mix fifty cubic centimeters of the oil under test with fifty cubic centimeters of benzol in a centrifugal graduate. Turn centrifuge until a clear line of demarkation is visible between the oil, water, and sediment. Centrifuge must be run at designed speed as running at other speeds makes a material difference in determination of amount of sediment.

The oil may be thinned with gasoline, but this is objectionable as many of the asphaltic hydrocarbons are insoluble in gasoline and are therefore precipitated as sediment, but its use will give a true indication of the water present.

Oil analysis.—Though fuel oils are made up of a large number of different chemical compounds, known as hydrocarbons, and though two oils may differ widely in the proportions of the various hydrocarbon compounds they contain, the ultimate analyses of different oils vary but a few per cent. Carbon and hydrogen in percentage of 84 to 87 and 11 to 14, respectively, are the principal elements to be found. Small amounts of oxygen, nitrogen, and sulphur are always present.

Oil explosions.—Fuel oil itself is inert, non-explosive, very difficult to ignite in bulk, and not capable of spontaneous ignition. The vapor from this oil, however, is explosive when mixed with air. This vapor is heavier than air and tends to accumulate in low levels, such as bilges and bottoms of tanks, where it may remain undiscovered until ignited by a naked light

or spark. It is always present in a partly filled oil tank, or one that has contained fuel oil and from which the vapor has not been removed by artificial means, and it is expelled through the vents from the fuel oil tanks while they are being filled. A leak allowed to continue in any part of the oil-burning system may result in an accumulation of this explosive vapor, unless such leak is located in the path of air to the furnace. Ignition of the vapor may be caused by an open light, electric spark, or spark made by striking metal, heat of the filament of a broken electric lamp, smoking, sparks from funnel or galley, or fires under boilers. An oil fire can best be extinguished by foam extinguishers or carbon-dioxide extinguishers. Sand and steam are also efficacious.

Fueling facilities, conditions, methods of delivery, and prices of fuel oil are published from time to time in Bureau of Supplies and Accounts circular letters.

Specifications for fuel oil are issued in leaflet form by the Navy Department and may be obtained on request from the Bureau of Supplies and Accounts.

All tests shall be made in accordance with the methods for testing fuel oils as described in Navy Department specifications.

2. COAL

Coal.—Coal is an agglomerate of the solid degradation products of decayed vegetation which consisted of sedges, reeds, tree ferns, club mosses, and trees akin to the pine, together with such of the original bodies as have resisted to a greater extent the actions of time, temperature and pressure to which the material was subjected in the transformation to coal.

Constituents.—The elementary chemical constituents of coal are *carbon, hydrogen, oxygen, nitrogen*, and various mineral constituents which make up the *ash*. These elements are combined in coal in some of the most complex substances known to organic chemistry. The determination of the percentages of carbon, hydrogen, oxygen, and nitrogen is known as an "ultimate analysis." This form of analysis is seldom necessary in practical work and is mainly used in chemical investigations of the organic substance of coal.

For fuel and other practical purposes, coal is considered as being composed of *moisture, volatile matter, fixed carbon, ash*, and *sulphur*, a statement of the percentage of each of these items being known as a "proximate analysis."

Moisture.—The moisture in coal consists of the natural water combined in or held mechanically in the coal particles before mining, plus such atmospheric moisture and rain as may have been added while in transit

in storage. The amount of moisture in a given coal varies greatly after it is mined, increasing or decreasing in a short period of time according to atmospheric conditions.

Volatile matter.—The volatile matter consists of many complex combinations of mainly carbon, hydrogen, and oxygen, which form during the early stages of the combustion process and which are manifest in the gases and tarry or smoky vapors issuing from the surface of a fuel bed. Under suitable conditions volatile matter can be burned to prevent smoke, but not all of the volatile matter is combustible.

Fixed carbon.—The fixed carbon is virtually coke, or that portion of the coal (minus the ash) which remains after distillation of volatile matter. In laboratory work, 100 minus the sum of the percentage of moisture, volatile matter, and ash is arbitrarily termed the per cent of fixed carbon. Thus all possible errors are thrown into this item, which, however, is of the greatest importance in fuel calculations or comparisons.

Ash.—The ash consists of the non-combustible residue remaining after combustion is complete. Its composition and amount vary greatly, according to the origin and nature of the coal from which it is derived. There are two sources of ash: from the coal substance itself, which is known as inherent ash and from the enclosing rock strata of the coal bed and so-called "partings" of clay or slate within the bed, which is known as extraneous ash. The amount of inherent ash is usually fairly constant for the same coal. The amount of extraneous ash varies according to the care exercised in mining and preparation for market. Ash is the most important constituent to observe in coal, both because of its varying amount and because of the effect of its fusibility upon the steaming quality of the coal.

Clinkers consist of fused ashes, and result from subjecting the ash to a higher temperature than its fusing point. Analyses of ash, as ordinarily made, are of little value in judging clinkering properties, but it is now possible to determine the actual fusing point and thus select coals of the highest fusing temperatures. Ash with fusing temperature above 2,500° seldom forms troublesome clinkers.

Sulphur most commonly occurs in the form of iron pyrites either in large, bright, metallic masses or small, brassy scales. With few exceptions, its effect upon the fuel value of coal is negligible, and, while it is customary to give the amount in any analysis, it is of more interest to the metallurgist than to the marine engineer.

Calorific value of coal.—The heating value of coal is stated in terms of British thermal units in America and England, and calories in most European countries.

Many tables and formulas have been devised for the calculation of the calorific value from proximate analyses, but these have proven satisfactory only on samples of coals from which the tables or formulas were derived.

The calorimetric determination of the B.t.u. value of coal should be entrusted only to an expert, and if results are to prove reliable these tests must be made with properly taken samples.

Interpretation of analyses.—Coals are customarily compared in terms of their analyses, and as there are three general modes of statement, the analyses must be on the same basis to be comparable. These three modes of statement are "As Received," which shows actual analysis of sample as received at the laboratory; "Dry Coal," which is recalculated from the actual analysis, eliminating the uncertain moisture element, and "Moisture and Ash Free" (M & AF) erroneously called "combustible basis." In this last both moisture and ash are recalculated out of the "As Received" basis for the purpose of showing the true proportions of volatile matter and fixed carbon, and the heating value per pound thereof.

TYPICAL ANALYSIS OF COAL, ILLUSTRATING EFFECT OF MODE OF STATEMENT
ON SAME SAMPLE

	<i>As received</i>	<i>Dry coal</i>	<i>Moisture and ash free</i>
	%	%	%
Moisture	8.29		
Volatile matter	31.19	34.01	38.56
Fixed carbon	49.69	54.18	61.44
Ash	10.83	11.81	
Total	100.00	100.00	100.00
Sulphur	2.81	3.06	3.47
B. t. u. per lb.	11,837.00	12,906.00	14,636.00

NOTE: To calculate "Dry Coal" analysis from "As Received" basis, subtract the percentage of moisture from 100 and divide the result separately into volatile matter, fixed carbon, ash, sulphur, and B.t.u. To calculate the "Moisture and Ash Free" analysis from "Dry Coal" basis, subtract "Dry Coal" ash from 100.00 and divide the result into each of the other "Dry Coal" items as in the case of calculating "Dry Coal" analysis. The "Dry Coal" basis of analysis is the one generally used in engineering. It eliminates all uncertainty, concerning the accuracy of the constantly changing moisture percentage. In any analysis moisture and ash have the same effect on B.t.u. value when determined by calorimeter. These simply act as dilutants of the combustible part of the coal. Starting with the M & AF B.t.u. value (sometimes called Pure Coal Value), the addi-

tion of each per cent of ash or moisture reduces the M & AF B.t.u. value by an equivalent percentage. The M & AF B.t.u. value for many coals varies so slightly in a large series of analyses that for practical purposes an average may be regarded as a standard from which to determine approximately the "Dry" and "As Received" B.t.u. value of other samples in which the ash and moisture only are known. The M & AF basis is frequently of value in identifying coals from analyses which show extraordinary percentages of moisture and ash.

Classification of coals.—Coals are classified according to both their physical and chemical characteristics. No classification based entirely on chemical analyses is satisfactory, owing to the overlapping of the various classes or the gradual merging of one class into the other. The fuel ratio, fixed carbon $\div$ volatile matter, is the most common basis of classification.

GENERAL CLASSIFICATION OF COAL

	<i>Volatile matter per cent</i>	<i>M. & A.F. B. t. u.</i>	<i>Characteristics</i>
Anthracite	3 to 8	14,500 to 15,000	Hardness and distinctive analysis
Semi-anthracite	8 to 12	14,500 to 15,000	Hardness and distinctive analysis
Semi-bituminous	15 to 28	15,400 to 15,900	Low volatile, high B. t. u. friability
Bituminous	30 to 40	13,500 to 15,500	Wide variety
Sub-bituminous	30 to 45	13,000 to 13,500	High moisture, 10-25 %
Lignite	40 to 60	11,000 to 13,000	Brown color, excessive moisture, 30-40 %

Marine coals.—Semi-bituminous and bituminous are the coals best adapted to marine boilers.

Semi-bituminous, also known as "low volatile" or "smokeless," is a cooking coal of first quality for marine use. Pocahontas and New River brands in this country and British Admiralty coals of South Wales belong to this class. In addition to its low volatile and high B.t.u. characteristics, it is usually rather friable or soft, resulting in considerable slack or fine coal if much handled. This slack, however, cakes in the furnace.

Bituminous.—This class embraces a wide variety of coals, both in analysis and physical characteristics. Owing to the long use of "bituminous" as a general name for any coal that was not distinctly anthracite, many coals are still thus designated which are as distinct in type as the semi- and sub-bituminous coals which are now separated from the general

class. The designation may be taken to mean simply high volatile coal.

Sizes and grades.—Coal as mined consists of a mixture of irregular pieces, ranging from large lumps to fine dust. This mixture is known as “run of mine” and, in America, is the grade generally used for bunker purposes, as it is always in greatest supply at coaling ports. Run of mine is separated into various sizes by passing it over and through screens of various meshes. There are no standard screens, consequently sizes vary widely in different districts and even in the same district. The most common screened sizes, in the order of their relative size, are “lump,” “egg,” “nut,” and “slack.”

At some mines it is the practice to separate the entire output into these sizes for convenience in removing impurities, the sizes being recombined later into run of mine. This recombined run of mine appears, while still in cars, to be poorly mixed, but the process of unloading into bunkers completes thorough mixing.

Washed coal, whether as run of mine or screened sizes, is coal from which the heavy impurities constituting the extraneous ash have been removed in water by taking advantage of the difference in specific gravity of coal (about 1.28) and of impurities (from 1.4 to 2.0). The dry coal is fed to tanks, called jigs, through which water flows. A strong upward pulsation being given to the water, the good coal floats over the side of the jig and the impurities gradually work their way against the upward flow of water to the bottom, where they are removed at intervals.

Washed run of mine and slack, as loaded at the mines, contain a high percentage of moisture depending upon the amount of fine coal. This not only holds large quantities of water but also prevents rapid draining of the car. The lower ash content of washed coal more than compensates for its higher moisture content as compared with the same unwashed coal in the dry state.

Impurities in coal comprise “slate,” “bone,” “sulphur band,” pyrites, rock, or any other ash forming material which becomes mixed with the coal in the process of mining. Of these the most common are slate and bone.

Slate is a term widely used to cover most of the foreign material and correctly designates pieces of shale or fire clay from the roof or floor of the mine, or from layers within the coal bed itself, known as partings. Slate can be easily distinguished by its color and flat shape, and is unmistakable when handled.

Bone is either smooth, shaley, or rough, sandy material containing sufficient carbonaceous substance to give it the appearance of coal. It ranges from 25 per cent upward in ash. In many coal beds bone has the

same fracture as the associated coal, and is difficult to distinguish. It usually has a dull luster as compared with its coal, and can be recognized by this or its greater density.

Selection and inspection of coal for marine use.—The characteristics desired in selecting a marine coal are: (1) maximum heat value or B.t.u. per cubic foot of bunker space, thereby increasing steaming radius or allowing more cargo to be carried; (2) low volatility, if obtainable, to minimize soot and tube sweeping; (3) high fusing temperature of ash (2,450° F. or higher) to reduce clinker troubles and frequent cleaning of fires; (4) sufficient lump coal in run of mine to start fires quickly.

These qualifications must be learned from experience with different coals, although the general reputation, description, and analysis of a given coal will provide some means of judgment. The space required per ton of coal and the analysis can usually be obtained from the supplier, in which case a comparison under (1), of coals available may be made by the following formula:

$$\text{B.t.u. per cu ft. bunker space} = \frac{2,240 \times \text{B.t.u. per lb. of coal}}{\text{cu. ft. per ton of coal}}$$

Coals vary considerable in space per ton occupied, ranging from about forty to over fifty-five cubic feet per ton of 2,240 lbs., and it is important to take this into consideration when comparing B.t.u. values.

The inspection of a lot of coal before delivery is made to the ship is not to be wholly relied upon as a means of determining its quality, but is of value in comparing different lots of a known coal and in showing in an unknown coal whether it (1) contains large pieces of slate or other impurities; (2) is coarse (containing a good percentage of lumps) or is fine (containing much slack); (3) is dry or wet.

Spontaneous combustion and storage.—The spontaneous combustion of coal is caused by the absorption of oxygen from the atmosphere with resultant evolution of heat, which, in a large mass or pile of coal (itself a poor heat conductor), accumulates until the temperature rises to the ignition point when, if sufficient air circulates through the mass, the pile takes fire. The oxidation is greatly accelerated as the temperature rises and it is believed that resinous substances of the coal, on account of their great affinity for oxygen, not only play a leading part in the action, but the varying amount in different coals probably explains why some coals are more liable to spontaneous combustion than others. The theory that sulphur is the cause of spontaneous combustion has been proven erroneous. Pyrites or sulphur balls are rapidly oxidized at ordinary temperatures, but the amount contained in coal is seldom sufficient to cause trouble,

Pyrites is a contributing factor, however, especially in wet coal, as the rapid oxidation of the pyritic particles distributed throughout the coal causes these particles to swell and split open the coal lumps, thereby exposing fresh coal surfaces to further oxidation. The popular opinion that the more bituminous (or higher volatile) coals are the most dangerous also is an unwarranted conclusion.

When taken from the mine, coal begins to absorb oxygen, and this absorption slowly continues until it is saturated. While coal is being handled and transported in cars, the heat formed by oxidation is dissipated by the large exposed surface, and therefore there occurs no appreciable rise in temperature. During the first period of handling, the surface of the lumps and particles of coal become partially or wholly oxidized or seasoned, but when the coal is dumped into ships' bunkers or ground storage, much breakage and disintegration takes place which exposes entirely fresh surfaces to the atmosphere ready for oxidation.

There is no general rule that can be followed for the prevention of spontaneous combustion, as the conditions under which coal must be stored, particularly aboard ships, vary greatly.

The wetting of coal to prevent spontaneous combustion has been strongly advocated, but unless at least fifteen per cent of water is added (with consequent loss of carrying capacity) nothing is gained, and if sulphur is present in the form of finely divided pyrites, a slight wetting increases the danger to fire.

An attempt at ventilation is also dangerous since it is manifestly impossible to reach the interior of the coal mass with a sufficiently strong air current to carry off the heat. Inadequate ventilation, therefore, becomes an added danger through supplying oxygen. Constant vigilance aboard ship and the using up first of coal in a bunker which is getting hot is the most practicable means of avoiding trouble; 150° F. may be considered the danger point beyond which action is very rapid. When practicable, coal stowed against hot bulkheads, over boilers, or against flues or steam pipes should be used first.

On shore, the storage of coal in low piles of 500 to 1,000 tons about ten feet in height, rather than in one large pile, is not only the safest measure of prevention but provides means in case of fire of localizing and reaching it easily.

U. S. Navy coal.—Section 3728 of the Revised Statutes of the United States provides, that, "In purchasing fuel for the Navy or for naval stations and navy yards, the Secretary of the Navy shall have power to discriminate and purchase, in such manner as he may deem proper, that kind of fuel which is best adapted to the purpose for which it is to be used."

The Navy Department has made it the practice to supply naval vessels with the best semi-bituminous coal obtainable. Strictly speaking, the coal is not purchased under specifications, but the coal delivered must meet the following requirements as to quality:

"Coal to be the best quality, Navy standard steaming, or equal, semi-bituminous, run of mine, with at least 40 per cent lump, suitable and acceptable for the uses of the naval service.

"Coal must be dry and practically free from slate, dirt, sulphur, and other impurities, subject to the usual inspection and test, and must weigh 2,240 pounds per ton, the weight to be determined in a manner satisfactory to the Government."

Navy standard steaming coal is coal supplied from mines on the Navy acceptable list, the delivery fulfilling the requirements as to moisture, percentage of lump, and cleanness.

The Navy acceptable list is a list of mines that have supplied coal which has proved satisfactory for use on board naval vessels and whose output is controlled by reliable suppliers that may be depended upon to deliver the required amount of satisfactory coal under all conditions of the coal and labor market.

Mines are liable to suspension or elimination from this list if the deliveries of coal are the subject of complaint by the ships of the fleet or the supplier fails to fulfill the conditions of his contract.

When the coal which the bidder proposes to furnish does not come from a mine on the Navy acceptable list, the bid will not be considered if the coal shows an analysis indicating low quality, by showing more than the following:

(a) Moisture in "delivered coal"	3 per cent
(b) Ash in "dry coal"	7.5 per cent
(c) Volatile in "dry coal"	20 per cent
(d) Sulphur in "dry coal"	1.25 per cent

and less than:

(e) B.t.u. per lb. of dry coal	14,700
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If the analysis of the coal indicates quality equal to or better than this, the bidder may be awarded a contract for a small amount of coal, the contract being subject to cancellation if the coal proves unsatisfactory for use on board ship, or the amount called for being subject to increase if the coal proves satisfactory, in which case the mines supplying the coal are placed on the Navy acceptable list and the coal is classed as Navy standard steaming coal.

Sampling.—The accuracy of an analysis depends principally on the care used in securing a representative sample. Only one gram of coal is

used as the unit for actual analysis in the laboratory and the ultimate object to be gained in sampling is to have that final gram of coal possess all the characteristics of the entire lot of coal under investigation. It should contain its due proportion of good coal, poor coal, bone, and slate in the same ratio in which they exist in the entire lot. The laboratory end of the sampling has been standardized and this work, as well as the analysis, should be entrusted solely to an expert coal chemist with proper equipment. The sample delivered to him should be not less than ten pounds unless taken by an expert sampler equipped with a crusher and mechanical means of mixing and reducing the bulk of the original sample.

The problem in sampling a mixture like run of mine is to secure the same proportion of slate and other extraneous impurities in the sample as exists in the entire lot. For example, 100 tons of coal may contain one ton of slate representing one per cent of ash, some of this slate being in 2-pound pieces. If a 25-pound sample were taken in which one of these 2-pound pieces of slate were included, it would contain nearly ten per cent ash in form of slate instead of the correct one per cent. If 100 pounds were taken, including the same slate, the slate ash would be two per cent and in taking the larger amount the danger would be incurred of securing more than one large piece of slate. The size of the impurities, therefore, is the governing factor in sampling coal, the effect of the chance inclusion of extraordinarily large pieces of impurity being overcome by taking very large original samples. In general, the larger the impurities observed, the larger the sample should be, and 1,000 pounds has been adopted as the standard sample covering the majority of cases.

Briefly, the approved sampling method is as follows:

(1) Samples should be taken when entire lot of coal is exposed, as when being loaded or discharged. Avoid sampling piles or tops of cars.

(2) Sample should be accumulated in increments (shovelfuls) of 20 to 25 pounds at regular intervals, no attempt being made to secure a definite percentage of the lot.

(3) Endeavor to secure in each increment the same amount of lump, coarse, and fine as is contained in the coal from which taken. The best way to accomplish this is to sample blindly by putting into the sample whatever is taken on the shovel or sampling tool.

(4) The sample while it is being accumulated should be crushed on a large piece of canvas, iron plate or cleanly swept deck, unless a hand mill or mechanical crusher is available. Protect sample from rain or dust and other foreign matter.

(5) After the whole sample is secured, it should be mixed by spreading it out in a thin layer, one shovelful over the other; then scraped into a

cone-shaped pile which is divided through the center into four equal quarters. Opposite quarters or quadrants are to be discarded and the remaining ones mixed and again crushed in accordance with the following table, this quartering, mixing, and crushing being continued until the final sample for the laboratory is obtained:

	<i>Sample as taken</i>	<i>From first quartering</i>	<i>From second quartering</i>	<i>From third quartering</i>	<i>From fourth quartering</i>
Weight of sample	1,000	500	250	125	60
Size to be crushed to before quartering, in.	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$

The $\frac{1}{4}$ -inch coal sample (60 pounds) should be successively mixed and quartered until 8 to 10 pounds remain for laboratory, or if two or three duplicates are required, this 60 pounds may be divided into halves or thirds.

There is a loss or gain of moisture during the time consumed in sampling so that the moisture will not be correctly represented.

If the moisture determination is important, take a separate increment of about 10 pounds, with every alternate shovelful of the main sample. Break the large pieces down to about 1.5 inches to 2 inches in size while on the shovel and quickly drop into a tightly covered container. When sampling is completed, form the moisture sample into a pile and rapidly quarter down to 10 or 15 pounds without further crushing or mixing. This sample should be sent to the laboratory in an air-tight container.

CHAPTER VII

OPERATION OF BOILERS

1. OIL-FIRED BOILERS

Preparing to light off and cut in.—The following is the procedure to be followed before lighting off and cutting in an oil-fired boiler.

Remove the smoke pipe cover and slack evenly the smoke pipe guys.

If the oil system is new or if it has been idle, for a long period, blow through the system with air when starting it up, in order to see that the system is free from waste, flakes of shellac, red lead, and dirt.

Inspect and clean all strainers, renewing any defective wire mesh.

Clean all the atomizing tips, place and properly adjust them in the air registers, and test out the working of the air registers. Close the individual atomizer throttle valves.

The following precautions are to be taken to free the bilges and furnaces of explosive gases:

(a) Pump out and steam or wash out all bilges. (Steam or hot water should not be used on bilges coated with bitumastic or similar coatings.)

(b) Wipe up all oil on floor plates or elsewhere.

(c) Blow out furnaces with air or steam, or, if neither is available, thoroughly ventilate.

(d) Inspect for and remedy all oil leaks.

Examine all casing doors to see that they are closed and airtight. (If the boilers are B. & W. boilers the front and back casing doors should be left open until a boilermaker can take up on leaky handhole plates, if any, as the steam pressure rises.)

Open the air cocks, the gage-glass cocks, and see that try cocks are in efficient condition.

If the boiler has been open, close the handholes and manholes, and set up on the handhole and manhole plate fittings. Close the drain cocks, the try cocks, the surface and bottom blow valves and sea connections.

Fill the boiler with fresh water until the water is just within sight above the bottom of the gage glass. Do this with the auxiliary feed pump in order to test the auxiliary feed pump and line.

If the boiler has been full, examine the surface blow valves and sea valves; they must be closed and not leaking.

Run down or pump down the water until it is just out of sight in the gage glass, then close the bottom blow valve, open the auxiliary feed

stop, and check and bring the water level to just within sight above the bottom of the gage glass. (This tests the auxiliary feed pump and line.) Examine the drain cocks to see that they are closed.

Open and close the safety valves by hand. Raise the water level in the boiler about one-half inch by opening the main feed check-and stop valves to insure that these valves are functioning properly. If the boiler is a Scotch boiler circulate the water with hydrokineter or auxiliary feed pump.

Ease up the boiler main steam stop-valve stems with the deck control gear without lifting the valve disks off the seats, in order to prevent sticking when the valve heats up. If the boiler has a superheater, open wide the boiler main steam stop and the superheater inlet valves. Close tightly the superheater by-pass valve. Ease up on the boiler cut-in (superheater outlet) valve stem in order to allow for expansion when heating up.

Open all cocks and valves in the line to the boiler steam gage. If air chambers are fitted on the oil lines, drain them and charge with compressed air.

Open proper valves in oil-pump suction line. If steam is available, start the oil pumps and put pressure on the delivery line to the atomizers, if steam is not available a hand pump will keep two or more of the small size atomizers in operation up to 200 pounds oil pressure. In lighting off 150 pounds pressure on the oil line is sufficient. (By-pass the oil meter until ready to light up, otherwise it will operate while the air is being pumped out of the line in which oil is being circulated.)

Have blowers warmed up and ready to turn over. Run slowly before lighting first burner to prevent danger of flareback. Drain or pump over-board water that has settled in the oil tanks. If the oil is very cold and viscous and pumps have difficulty in getting a suction, use heating coils provided in the tanks. If steam is on the ship, cut in the fuel-oil heater.

Lighting off.—Open and light off the center atomizer, which must have a "port" size atomizer tip or sprayer plate, using a hand torch placed near and just under the atomizer. *Stand well clear* to avoid a flareback.

A suitable torch is a rigid wire rod two and one-half to three feet long, to one end of which is secured a few turns of asbestos wicking which may be dipped in oil.

If the brickwork is new, the boiler must be heated slowly, but at other times, or in emergency, the burners may be cut in rapidly in water-tube boilers.

If there is sufficient draft extra burners adjacent to both sides of the center may be lighted. Always use the torch when lighting off extra burners when the furnace is still relatively cold. If steam is on the ship the blowers should be run. After steam is generated and the furnace hot,

i.e., the brickwork is intensely hot, additional burners may be safely lighted from adjacent ones that are in operation.

But under no circumstances, no matter how hot the furnace may be, if all burners are temporarily secured, should an attempt be made to relight from the incandescent brickwork. This practice has occasioned the most serious accidents. Always use the torch if all burners are out.

As the water level rises from expansion during heating of the water in the boiler, and frequently after steam has formed, check the gage-glass water level with that shown by the try cocks.

As the boiler heats up have the ship's boilermaker set up on any leaky handhole plates, manhole plates, or other fittings. For this purpose only the proper spanner should be used, normally a leverage of 24 inches for manhole and 19 to 24 inches for handhole plate fittings.

After steam has formed and has blown sufficiently to exclude all the air from the boiler, close the air cocks.

Check the steam gage to see that it at once registers pressure.

When the boiler pressure reaches 100 pounds (gage) lift the boiler safety valve by hand and allow it to reseat at once.

Check the working of the gage glass by opening its drain and blowing through.

Lift the safety valves by steam at the prescribed pressure. If necessary adjust the setting of the valves. If the safety valves cannot be adjusted to lift properly, let the boiler die out.

See that the water in the boiler is kept at the steaming level.

If the line to which the boiler is to be connected is cold, warm it up by using the main steam stop by-pass or by cracking the boiler main steam stop valve, or if a boiler with superheater, the cut-in (superheater outlet) valve. During the process, watch the main steam line and set up on any leaky joints; watch the slip joints to see if they are free; use and watch the steam line drains and traps, opening the trap by-passes if the volume of water is too great for the traps to handle.

Cutting in.—*Boilers not having superheaters.* With boiler pressure five to ten pounds above the line pressure crack the boiler main steam stop valve (or its by-pass valve, if one is fitted) from the firerooms, rather than from a station outside of the firerooms, and allow the pressures to equalize; then slowly open the steam stop valve.

Boilers fitted with superheaters. Open the boiler cut-in (superheater outlet) valve with similar precautions as above, but, if no drain is fitted to superheater, the boiler pressure should be five to ten pounds below the line pressure, in order to drain the superheater into the boiler, if such draining is necessary.

If a drain is fitted on the superheater, follow the procedure as given above for boilers not having superheaters.

Time required to raise steam.—The length of time required to raise steam in any boiler depends upon the type, size, and condition of the boiler. Except in cases of emergency, at least six to twelve hours shall be occupied in raising steam from cold water in fire-tube boilers. While raising steam in this type of boiler, half hourly temperatures of the boiler water shall be taken and the fires shall be checked or accelerated as may be necessary to distribute the heat evenly throughout the prescribed period of time. If heat is applied too rapidly, the boiler parts will not be heated evenly and the severe strains set up will cause leaks at the calked seams, rolled joints, etc. While warming up a fire-tube boiler the water shall be circulated continuously either by means of the hydrokineter or the auxiliary feed pumps. In water-tube boilers steam may be raised in much less time. The time required under ordinary circumstances varies from one to three hours, depending upon the type and size of the boiler. If the brickwork is new a longer time will be required.

Cutting out and securing.—The following is the procedure to be followed in cutting out and securing an oil-fired boiler.

Close the oil valves to the atomizers one by one, at the same time closing the air registers. Slow down the oil service pump as the atomizers are shut off, to prevent the pressure from building up. Shut off the steam to the oil heater to prevent excessive heating and carbonizing of the oil as the flow is reduced. Slow down the blowers. When all atomizers are closed, secure the oil lines and oil pump.

Remove the atomizers at once, drain contained oil into a closed bucket, and immerse the tips in kerosene until opportunity permits cleaning and filing.

Close up the furnace tightly to prevent access of cold air to the heated interior, as sudden cooling off will cause serious damage to the refractory furnace lining and probably cause tubes to warp. (This is especially necessary when a blower is kept running for another boiler in the same fireroom.)

When the boiler ceases to require feed because of the condensation of steam in it, thus becoming a drag on the others connected to the steam line, close the boiler steam stops and *fill the boiler to three-fourths glass.*

Run a blower long enough after shutting off oil supply, when all boilers in a fireroom are being secured, to insure that all oil on the furnace floor is consumed and that the furnace is cleared of all gases.

If at sea, or at an anchorage where permitted, flush and pump out bilges. The restrictions of port regulations shall be strictly observed regarding the pumping overboard of fuel oil or oily water from the bilges. Even

where there are no specific port regulations on the subject, oil shall not be pumped overboard in restricted waters where it will contaminate beaches, kill fish, or otherwise cause injury or inconvenience.

The firing of an oil-fired boiler.—For efficient operation the personnel of the fireroom force should be thoroughly acquainted with every detail of the fireroom installation. Each member of the fireroom force should understand the operation and purpose of the atomizers, registers, pumps, heaters, blowers, strainers, and all other equipment. It is particularly important that each member of the fireroom force should have such thorough knowledge of the location and proper manipulation of all valves and manifolds that he would be able to locate and manipulate them properly even when the fireroom is in utter darkness.

The general requirements for the efficient firing of an oil fired boiler are:

(1) *Oil supply.* The proper quantity of oil must be supplied to obtain the desired rate of combustion.

(2) *Air supply.* The proper quantity of air must be supplied to support the combustion of the oil burned and the *excess air* must be reduced to a minimum.

(3) *Mixing the air and oil.* The oil must be finely atomized just before it comes in contact with the air for combustion, and the air for combustion should be thoroughly mixed with this finely atomized oil.

(4) *Maintaining the furnace temperature.* A high furnace temperature is necessary in order to assist in obtaining complete combustion of the oil. For this it is necessary that the boiler be so constructed as to have sufficient refractory surfaces.

The first three general requirements will now be considered in more detail.

Oil supply.—The amount of steam generated depends upon the amount of oil supplied to the boilers. For oil-fired boilers on board naval vessels the oil which can be supplied to the boilers ranges from the amount supplied with one burner fitted with the smallest atomizer to the amount supplied using the full battery of boilers with all burners fitted with atomizers of the largest size.

Five means are provided to vary the rate of combustion of the oil in order to meet the variations in steam demand. These means are:

- (1) Size of atomizer used.
- (2) Number of atomizers used per boiler.
- (3) Oil pressure used.
- (4) Number of boilers used.
- (5) Number of blowers used and their speed (this varies air pressure).

If the steam demand can be easily met with one atomizer, that atomizer should be selected whose capacity will handle the normal load with an oil pressure not less than 200 pounds.

The most central burner should always be used first, and its capacity should be utilized to the limit set before using additional burners. One burner only should be used when the load is nearly constant. When it is necessary to use more than one burner the number in operation should be kept symmetrical to the most central one in order to maintain the combustion in the center of the furnace and as far as possible from the tubes and furnace walls.

With a specified number of boilers, and with a specified size of atomizer, increase or decrease in load can be taken care of in two ways, namely, increasing or decreasing the oil pressure with each variation in the load, or by increasing or decreasing the number of atomizers in use.

Meeting changes in load by varying the oil pressure requires experienced, efficient, and well-trained personnel and is most successful when the pumps are located in the firerooms. However, this method should not be attempted if the change in load would necessitate an increase or decrease in oil pressure of more than fifty pounds.

Taking care of changes in load by cutting in or out burners requires for best operation that experiments be conducted to obtain data for curves giving the approximate air pressure to be carried at 150-, 200-, 250-, and 300-pound oil pressures, with different sizes of atomizers and different number of burners in use. These curves enable the operating personnel more quickly to arrive at the approximate proper air supply after conditions have settled down. Further adjustments can then be made for different operating conditions which are caused by air leaks, atmospheric conditions, and grade of oil in use.

The engineer officer must decide, after careful experiments with his plant, which of the two systems gives the best results with his installation.

Whichever system is used, the operating personnel must be taught that, whatever the general conditions are for meeting the load changes, the oil must be burned in such a manner that a light brown haze is being emitted from the smoke pipes.

For good combustion a steady oil pressure is essential. Little trouble is experienced from fluctuating pressures with pumps of the rotating plunger or screw type, but with pumps of the reciprocating type, air chambers are necessary to cushion the oil and to absorb the pulsations. These air chambers should always be kept charged with compressed air, either by the use of the snifting valves if fitted, or by the compressed-air installation.

Air supply.—A definite amount of oxygen is required for every pound of fuel oil that is completely burned. This oxygen is obtained from the air, the quantity of air necessary to supply the required amount of oxygen varying slightly with atmospheric conditions.

For average fuel oils the amount of air theoretically required varies between 13.8 and 14.4 pounds per pound of fuel or expressed in cubic feet, from 180 to 200 cubic feet of air per pound of fuel depending on the temperature of the air and the calorific value of the fuel. All air that enters the furnace above the amount necessary to completely burn the oil is *excess air*. This air enters the furnace at fireroom temperature, usually 90° to 110° F., absorbs heat, and passes out of the boiler at smoke pipe temperature, which may be anywhere from 500° to 800° F.

In practice, more air is necessary to insure complete combustion than is theoretically required. The smaller the percentage of excess air required to obtain perfect combustion in the furnace the more efficient the register and the furnace. On board ship the furnace efficiency may be considered very good if the excess air is kept below 50 per cent, and excellent if kept below 20 per cent.

Percentages of excess air as high as 200 are of common occurrence. *High percentage of excess air is the most serious and most common cause of low boiler efficiency.*

The heat carried away by the dry smoke-pipe gases is the largest of the boiler losses. This loss is unavoidable when the excess air is kept to a minimum consistent with complete combustion, but as the excess air increases, this loss rapidly mounts.

The most positive and direct aid in obtaining the maximum furnace efficiency is an intelligent use of the gas analysis apparatus. When correctly used it is a positive gage on the amount of excess air. However its use is not recommended until the operator has made a thorough and careful study of the subject, and fully appreciates the errors that enter into its use. Should its use be attempted, it should be placed under the direct supervision of an officer and he should not put too much dependence in the result until he has made a thorough study of the subject.

On board ship a good practical guide to high furnace efficiency is the appearance of the furnace in conjunction with the appearance of the smoke pipe.

If the flame is an incandescent white and the furnace walls are clearly discernible through the flame there is considerable excess air present. As the percentage of excess air is reduced, the color of the flame at the rear of the furnace becomes a pale yellow, then yellowish orange, and then orange red. In general with a well-designed installation in good condition oper-

ating with a minimum of excess air, the ends of the flame farthest from the atomizers are a yellowish orange or golden shade, the gases of combustion are colorless and the seams in the brick are just discernible.

At high rates of combustion, however, when the flame completely fills the furnace, the very high furnace temperature precludes the presence of these temperature colors. An incandescent and dazzling white will still indicate excess air but a reduction in the excess will only be indicated in the furnace by a softening in the intensity of the white flame.

A clear smoke pipe is deceiving. It may mean only a small amount of excess air or it may mean as much as 300 per cent excess. A clear smoke pipe is ideal if at the same time the gas analysis shows high CO_2 , very low O, and no CO; for example, 14.7 per cent CO_2 , 1.8 per cent O, 0 per cent CO.

It is good practice on board ship under the usual operating conditions to require the fireroom personnel to reduce the supply of air until a very light brown haze is emitted from the smoke pipe, assuming of course that dirty or streaky atomizers have been eliminated.

On ships where the top of the smoke pipe cannot be seen from the fireroom, an excellent alternative is to sight across the last pass, or at the base of the uptake. Two peepholes should be located, one on each side of the boiler, directly opposite each other and so that the vision through the boiler is not obstructed. An electric light with a clear bulb is then suspended near one peephole in the line of sight so that it can be clearly seen by an observer looking through the peephole on the opposite side. If the filament is clear and bright there is no smoke and probably considerable excess air. If it is just slightly dimmed and the furnace also indicates good combustion, the air supply is close to the right amount. If the filament shows dull red, the boiler is smoking considerably and more air is required.

The presence of smoke, however, does not always mean that there is insufficient air or that the CO is too high. Even when the air supplied for combustion is far in excess of that required, smoke is frequently caused by such defects as poor atomization, poor mixture of oil and air, unburned oil striking cooling surfaces, poorly designed furnaces, etc., and defects of this nature must be corrected and eliminated before proper oil and air regulation can be attempted.

For an oil-fired boiler the air supply is controlled in three ways: (1) the number of air registers opened, (2) the amount each air register is opened, and (3) by increase or decrease of fireroom air pressure using forced-draft blowers.

Mixing of oil and air.—The mixing of the oil and air is accomplished by means of two mechanisms—namely, the atomizer and the air control register.

Atomization of fuel oil is the breaking up of the liquid into minute fog-like particles. This is accomplished in three ways, each way being named after the kind of atomizer used, *i.e.*, (1) pressure (mechanical) atomization, (2) steam atomization, and (3) air atomization. The first method is the only one widely used for marine purposes.

In order to introduce into the furnace, the air supplied for combustion, and to introduce it in such a way that it thoroughly penetrates the oil spray and becomes intimately mixed with it in the right proportions and with a minimum of excess air, an air control register is used.

On board naval vessels the types generally used are, the "forced-draft air-control register" and the "natural forced-draft air-control register."

The underlying principle of the many types of pressure atomizers in practical use is, forcing oil under high pressure through passages in the atomizer so arranged as to give the oil a high velocity of rotation and thus break it up under the action of centrifugal force.

The rotation is accomplished by means of spiral or tangential grooves through which the oil is discharged at high pressure into a small cylindrical chamber. The tip end of this chamber is coned out and at the apex of this cone is the orifice through which the oil is discharged.

As the oil leaves this orifice it is acted upon by three forces: (1) gravity, (2) centrifugal action, due to rotation, and (3) translation pressure along the axis of the atomizer.

As a result, on leaving the atomizer orifice the small streams of oil break up into very fine fog-like particles. Each particle of oil tends to fly off in a straight line at an acute angle to the axis of the orifice, and also to the tangent of this orifice at the point left by the particle of oil. The path of each individual particle of oil would be a straight line as above, but for the downward curve due to the action of gravity. This gives a cone of finely atomized oil.

The fineness of the atomization depends upon:

- (1) *The design and mechanical construction of the atomizers.*
- (2) *Condition of atomizers as regards scratches and cleanliness.*
- (3) *The proper straining of the oil.*
- (4) *The heating of the oil to the proper temperature.*
- (5) *Below 100 pounds per square inch, the pressure at which the oil is delivered to the atomizer.*

The features of design and mechanical construction of the atomizers that affect the angle of spray and the fineness of atomization are:

- (1) The depth and shape of the orifice walls.
- (2) The size and shape of the whirling chamber.
- (3) The number of tangential slots that direct the oil to the whirling chamber.

- (4) The angle at which the slots are inclined to the axis of the burner.
- (5) The ratio of the combined cross-sectional areas of the tangential slots to the area of the orifice.

These proportions of the various oil passages are determined experimentally in order to get a proper angle of oil spray and thinness of oil cone.

Practical considerations, such as the size of furnace openings, the interference of one spray with another, and the formation of carbon on the boiler tubes, and furnace walls, make it desirable to keep the angle of spray at about 75° , i.e., $37\frac{1}{2}^\circ$ for the half apex angle of the cone.

Atomizers of different capacities or characteristics should never be used on a boiler at the same time.

Temperature and pressure of oil.—With pressure or mechanical systems, fuel oil is heated for the sole purpose of reducing the viscosity, i.e., increasing the fluidity, as this is an essential aid to fineness of atomization. Moreover, it is occasionally necessary, with oils that are extremely viscous at low temperatures, to heat the oil in order to reduce its viscosity so that the pumps will be able to handle the oil at full capacity.

In oil-burning vessels the *pressure* at the fuel oil service pump shall not exceed 300 pounds per square inch. The *temperature* of the fuel oil shall never be raised to or above the flash point in any part of the system except that part between the service heaters and the atomizers. However, in no case shall the oil be heated to a higher temperature than 20° below the flash point. Between the heaters and the atomizers, oil shall not be heated to a temperature higher than that necessary to reduce its viscosity to between twelve and eighteen seconds Saybolt Furol ($2 - 4$ Engler).

Fuel oil in the tanks, and in piping other than in the boiler service lines from heaters to boiler fronts, and in hot recirculating oil lines from heaters to tanks, shall not be heated to a higher temperature than that necessary to insure that the oil will flow freely to the suction of the service and booster pumps. The recirculating systems installed on some vessels contemplate the use of oil of such a high viscosity that it will be necessary to obtain a tank temperature of 150° F. In cases where fuel oil must be heated to such an extent as to cause undue heating of the magazines, artificial ventilation shall be employed to keep down their temperature within the prescribed temperature limits.

2. COAL-FIRED BOILERS

The procedure in lighting off and cutting in, cutting out and securing, and the operation, of coal-burning boilers, is similar in many respects to that followed for oil-burning boilers, and is covered in detail in the *Manual Engineering Instructions*.

The following are the requirements in a boiler furnace for burning coal economically, without smoke, and with a reduction in the deposits of soot on the boiler tubes:

(1) *A sufficiency of air.*

(2) *The air to be brought into intimate contact with the coal and the gases distilled therefrom.*

(3) *The mixture of distilled gases and air to be maintained at a temperature of incandescence in order that the gases may be burned before they become cooled below the ignition temperature by contact with the heating surfaces of the boiler.*

Due to naval boiler design the above conditions are difficult to obtain.

The two variables in the problem of obtaining the desired furnace conditions are the fuel supply and the air supply. Though having entirely different means of practical control these two variables depend largely one upon the other in their proper control.

Hand firing is generally used for marine boilers.

The various firing tools used are the shovel, slice bar, cleaning hoe, ash-pan hoe, pricker bar, and devil's-claw. The proper use of the above tools requires considerable judgment and skill.

Lighting off.—Before lighting off a boiler, a careful inspection should be made of the grate bars, brickwork, ash pan, ash-pit doors, furnace doors, baffles, and other fireside fittings, in order to ascertain that they are ready for steaming. The furnace may then be primed by spreading about four inches of green coal over the entire grate except the front near the furnace doors.

There a semicircular space of about $1\frac{1}{2}$ feet radius should be left bare to receive the kindling material. If available use live coal for starting the fire, putting two shovelfuls of fresh fire on the front of the grate near each furnace door to kindle the coal. Taking each door in turn push back the semicircle of green coal a few inches and spread the live coal forward to lightly cover the bare grate surface. "Wing" over the green coal pushed back. With this method of working up the fire the green coal burns back evenly across the entire grate without any tendency to drift forward toward one or the other sides of the grate and due to the winging over of the green coal the time necessary for lighting off is materially reduced. When the fire has burned back about one half the depth of the grate the front part of the fire should be coaled over. From then on the fires should be coaled over at regular intervals in order to build up the fire to the proper thickness by the time the boiler is cut in.

Firing systems.—The systems of firing are: (1) *The even spread firing*

system, (2) *The coking system*, (3) *The alternate side firing system*, and (4) *The alternate front-and-back firing system*.

For water-tube boilers the alternate side firing system is used. For fire-tube boilers the coking system is used.

With water tube boilers having more than one door to a furnace, at a signal to fire, from the time firing device, that part of the furnace that can be fired through one door is coaled over, and as soon as this is done, that part in front of another door is examined and if necessary leveled off. At the next signal to fire that part of the fire that was leveled off at the previous signal is coaled over, while another part of the fire reached through yet another door is leveled off. The fires are coaled over and leveled off taking the doors in turn. With water-tube boilers having only one door to a furnace, one side of the fire is leveled off and then coaled over on one signal, and the other side similarly worked on the next firing signal.

For uniform conditions the rate of firing should be regular. At any one firing signal the charge should not exceed three shovelfuls. Usually this amount should be used and the firing interval increased or decreased to meet the steam demand.

Air supply control.—An insufficiency of air, poor mixing of the air and combustible, and too low a temperature of the mixture will cause part of the fuel to pass off through the smoke pipe unburned.

An excess of air causes a heat loss due to raising the temperature of the excess air from that of the fireroom to that of the smoke-pipe gases.

The air supply controls on a coal-fired boiler are:

- (1) *Fireroom forced-draft blowers*—pressure draft control.
- (2) *Ash-pit doors*—pressure draft control.
- (3) *Dampers in uptakes*—vacuum draft control.
- (4) *Steam jet in uptakes*—vacuum draft control (when fitted).
- (5) *Furnace door*—boiler excess-air regulator.

The ash-pit doors and boiler dampers control the draft. The dampers are used to temporarily check combustion.

The forced-draft blowers and steam jet in the uptakes are used when the required rate of combustion is greater than that obtainable with natural draft.

3. FEEDING BOILERS

Water level.—In steaming boilers the water level shall be maintained at the proper normal water level. This proper normal water level varies with the type and design of the boiler, but in general will be as follows.

Scotch boilers.—Above the top plate of the combustion chambers.

Large-tube water-tube boilers.—Just below the circulating tubes, so that these tubes are free of water.

Small-tube water-tube boilers.—About two inches above the top row of circulating tubes. Exposing the circulating tubes slows the water circulating and thereby reduces the boiler efficiency.

With most naval service boilers the proper normal water level is obtained when the water gage glass is half full. However, there are some exceptions to this and the proper normal water level should be determined from a careful study of the ship's drawings, or if this is not clear from the drawings, the Bureau of Engineering's decision. The fireroom force will be instructed as to this normal water level, and also should be instructed as to what height to carry the water when there is a pronounced list on the ship.

When maneuvering, large fluctuations in steam demand will occur, with consequent large fluctuations in water level. Under such conditions experience must determine the proper water level to be maintained in order to prevent (1) priming when the steam is being drawn, and (2) the water level falling out of sight in the gage glass when the steam demand is reduced.

Indication of water level.—The two means provided for reading the water level in a boiler are (1) the water-gage glass and (2) the try cocks.

The water-gage glass has connections at top and bottom fitted with valves. If either of these connections is closed or even partially blocked, the water level indicated is a false one. Water-gage glasses shall be tested by blowing before connecting a boiler to the steam line and once each hour thereafter. At each blowing the glass shall be blown twice; first with one of the valves closed and second with the other closed. Both valves shall be opened wide after blowing and the accuracy of the water level indicated shall be checked by the use of the try cocks. The try cocks must be used to check the water level before connecting a boiler to the steam line and every fifteen minutes while the boiler is in use. Whenever the water level drops below the bottom of the gage glass the try cocks shall be used at once to determine the actual condition of the water in the boiler, in order that, should an emergency exist, the proper action may be taken promptly.

Control of water level.—The admission of feed water to a boiler is controlled by the feed stop valve and feed check valve. The feed stop valve is between the feed check valve and the boiler.

When the boiler is steaming the feed stop valve should always be kept wide open unless the feed check valve leaks so badly that even when entirely shut too much water is fed to the boiler.

The feed check valve is designed to control the water level by varying the amount of water fed. If feed regulators are installed they shall be kept in good condition and used, but not entirely relied upon.

Strict attention shall be given at all times to maintaining the height of

water in the boilers as nearly as possible at a constant level, which level shall be the proper normal water level established by the engineer officer. Sudden fluctuations in the water level due to great variation in the rate of feeding, are to be avoided as they are detrimental to boiler efficiency. The maintaining of a constant water level in water-tube boilers, especially oil-fired boilers is difficult and requires the strictest attention when feeding such boilers.

The adjustments of the water level should be made gradually and as frequently as necessary by a man specially detailed for that and no other duty. As long as a boiler is furnishing steam the feed supply shall never be entirely shut off, even for a short period.

Too high a water level will cause priming.

Low water is one of the most serious and most frequent emergencies that arise in a boiler room. It is generally the result of inattention on the part of the water tender and man tending the checks, or of their attention having been diverted to some other duty than the major one of maintaining the proper water level. Low water may also be caused by the following: failure of the feed pumps, the developing of leaks in the feed discharge line or elsewhere, a defective check valve, hot or low water in the feed tank, failure of automatic safety devices on water gages, or other defects combined with failure to use try cocks, causing incorrect water level to be shown.

Effects of low water.—With a hot fire under a boiler and with insufficient water in the boiler to absorb heat given off by the furnace, there is bound to result warping of the boiler casing, distortion of the boiler heating surface, destruction of boiler brickwork, serious steam and water leaks, and danger of boiler explosion.

Procedure in case of low water.—Whenever the water in any water-tube boiler falls out of sight in the gage glasses and below the lowest try cock the following shall be done:

If burning coal, deaden the fires with fire extinguishers, fire hose, or wet ashes, and then haul them.

If burning oil, shut off the oil supply to the burners.

Open the safety valves by hand continuously and relieve the pressure gradually, close the feed check valves, close the boiler steam stop valves, close the dampers, and the ash-pit doors, or, if burning oil, the air control register shutters. If possible, diminish the boiler-room air supply by stopping the blowers or trimming the ventilators away from the wind.

When the water level has once fallen below the lowest try cock after going out of sight in the gage glass the combustion shall be checked at once and no attempt shall be made to restore the normal water level by increasing the supply of feed water.

CHAPTER VIII

CLEANING AND MAINTENANCE OF BOILERS

1. CLEANING

Complete instructions for the cleaning and maintenance of naval boilers are to be found in the *Manual of Engineering Instructions*. These instructions contain all provisions for compliance with the *Navy Regulations*; if scrupulously observed and followed, delays, omissions, unnecessary work, and needless casualties will be avoided. Like any other piece of mechanism the life of a boiler depends upon the attention given to upkeep.

The cleaning of a boiler is generally divided into two operations:

- (a) *Cleaning of water sides.*
- (b) *Cleaning of fire sides.*

Maintenance repairs are made coincident with either of the above operations.

Cleaning of water sides.—Boiler feed water is seldom ever entirely free of such substances as gases or salts in solution and solids or oils in suspension, inorganic or organic in origin. Conversion by evaporation of the feed water into steam causes an almost complete separation of the water from the foreign substance. These substances such as salts and other solids remain in the boiler and generally adhere to the evaporating surfaces. An accumulation of these foreign substances is called scale. Scale acts as an insulator decreasing the evaporative efficiency.

The water sides of a boiler are periodically cleaned to remove the scale and deposits from the evaporating surfaces.

The cleaning is carried out as follows:

Loosening of scale.—As soon as it is possible for men to enter the boiler, the drums, tube ends, and all accessible interior parts are wire brushed.

The interiors of the tubes are cleaned by working a frayed wire cable back and forth several times through the entire length of each tube, or by the use of the following approved types of power-driven tube cleaners: (1) motor-driven, with flexible shafting, using sectional bristle wire brushes, (2) pneumatic-driven, fitted with solid steel cutters with serrated edges, (3) hydraulic turbine-driven, fitted with solid steel cutters with serrated edges.

These types are equally as effective, and much more rapid, for tube cleaning than hand-power methods.

Cleaning of scale.—After the scale has been loosened by the above methods it is removed from the surfaces by blowing each tube and the interior surfaces with air and washing the interior with fresh water.

Inspection.—Complete instructions for the inspection of the interior of a boiler, and the treatment of the defects found, are contained in the *Manual of Engineering Instructions* which may be briefly outlined as follows:

Pitting near the water line and near the projecting ends of the nipples and tubes. Internal fittings are inspected for signs of corrosion and to ascertain if the various passages are clean.

Warping of tubes, internal fittings, or sagging of drums.

Hydrostatic test. After general overhauling, a water pressure test is given the boiler to determine its tightness and the strength of its material. Complete instructions for conducting this test are contained in the Bureau of Engineering manual.

Cleaning of fire sides.—The formation of soot on the heating surfaces is caused by incomplete combustion of the fuel and to some extent the amount of ash that the fuel contains. As the soot is formed it collects on the heating surfaces, especially at the points where the circulation of the gases of combustion is sluggish. This formation insulates the heating surfaces from the gases of combustion thereby reducing the efficiency of the boiler. If the soot is allowed to remain on the heating surfaces for any length of time, sulphur in the gases will have a cumulative effect in the formation of sulphuric and other injurious acids, which will attack and corrode the surfaces.

In order to keep the boiler efficiency at a maximum and to reduce corrosion to a minimum the heating surfaces must be kept free of soot deposits. This operation is carried out in three steps:

- (a) *Preliminary blowing of tubes.*
- (b) *Removal of soot and ash.*
- (c) *Final blowing of tubes.*

Preliminary blowing of tubes.—If the soot is allowed to cool on the heating surfaces a hard scale will be formed which is difficult to remove. Therefore, before fires have died out, the cleaning doors are opened and the heating surfaces blown by working a steam lance back and forth between the rows of tubes.

Removal of soot and ashes.—As soon as it is possible for men to work in the boiler the soot and ash is removed by working saw-toothed lances, brushes, and small scrapers between the tubes.

Final blowing of tubes.—When as much soot as possible has been

removed by digging out, the tubes must be blown with lances, using dry compressed air, the fireroom being under heavy air pressure.

Inspection.—After the completion of the cleaning of the fire sides the external parts of the boiler are inspected as follows: casings and baffles inspected for air leaks and if necessary made airtight. Brickwork inspected for cracks and loose bricks. Tubes, for cleanliness, especially where tubes enter the drum, external corrosion to ascertain if the wall thickness is reduced beyond the allowed limit, and for warping beyond the allowed limit. If defective, the tube is renewed or plugged. Tubes are never straightened in place.

2. CORROSION

Corrosion is essentially the dissolving of metals and is generally accompanied by the subsequent oxidation of such metal in solution. It may take the form of a rust coating over the entire surface, called *general corrosion*, or it may be restricted to small areas, in which case it is termed *pitting*.

Causes.—Corrosion is due principally to the tendency of metals to dissolve in water, aqueous solutions and films of moisture. The metal so dissolved is readily oxidized in contact with free oxygen in the solution or above the surface of the solution. Three theories have been advanced to account for this action. All theories agree that the presence of moisture and oxygen are necessary conditions. The three theories are: (1) the acid theory of corrosion, (2) the hydrogen peroxide theory, and (3) the electrolytic theory.

(1) **The acid theory of corrosion.**—According to this theory, corrosion can occur only in the presence of carbonic acid or of some other acid in solution. It is supposed that such acids start the corrosive action and act as carriers of metal to oxygen, maintaining the process indefinitely. It has been shown, however, by numerous experiments, that corrosion may take place when iron is immersed in pure distilled water from which all carbonic acid or other acids have been expelled.

(2) **The hydrogen peroxide theory.**—This theory is based on the assumption that the formation of hydrogen peroxide is a necessary step in the formation of rust.

Experiments, however, show that while hydrogen peroxide does induce corrosion, it is not essentially a factor in all corrosive actions.

(3) **The electrolytic theory.**—The electrolytic theory is based on the fact that all metals tend to go into solution. This tendency to go into solution is electrolytic in character and is due to a difference of potential existing between the metal and the solution or between two metals im-

mersed in the same solution and metallically connected. A difference of potential between two points on the surface of the same metal is sufficient to cause the metal to dissolve, provided the solution is of lower potential than one of the points.

For example, if two metals are metallically connected in the presence of an electrolyte, one of them dissolves while the other is protected, the whole process being accompanied by an electric current flowing from one metal through the solution to the other metal. Where there is a single metal only in the solution, the different points on the surface which are at different potentials act in reality like different metals.

Metal so dissolved is readily oxidized by any free oxygen in the solution and is precipitated as rust, thus allowing more of the metal to dissolve.

The electrolytic theory is generally accepted, but a detailed discussion of it is beyond the scope of this work. It must be remembered, however, that a thorough understanding of the principles involved is essential to their practical application, and much damage may be done through ignorance and unintelligent application of the theory.

Corrosion in distilled water.—Experiments made with iron strips immersed in chemically pure distilled water show that corrosion occurs at varying rates, the amount of rust formed being dependent upon (1) the purity of the metal, (2) the amount of oxygen present in the water, and (3) the temperature of the water. In general the amount of corrosion will depend directly upon the amount of oxygen having access to the water and present in the water. Impurities in the iron, points of high potential on the surface due to the working of the metal, and the amount of carbon present in the metal, all influence the rapidity of corrosion.

Experiments have been undertaken with the view of excluding the air from the water by means of a protective film of oil on the surface. This method has proved ineffective however, since the oil absorbed oxygen from the air and further transmitted it to the water.

If all air is excluded from the water no corrosion occurs, but as soon as air is allowed access to the immersed metal, corrosion occurs rapidly.

When *pure distilled water* is made sufficiently alkaline, no corrosion occurs, but there is always the danger here that if the solution is not kept sufficiently alkaline, pitting will occur. It has been held that *chemically pure iron* immersed in pure distilled water will not corrode, but since chemically pure iron is not commercially obtainable, and must also be free from internal strains and improper hammering, it need not be considered.

The corrosive effect of a couple immersed in solution.—When two different metals are metallically connected and immersed in water or an aqueous solution, a difference of potential will be set up between them

similar to that in a battery, and if this potential is sufficiently great (depending on the character of the metals), one of them will dissolve while the other will be protected. Thus, in a copper-iron couple the iron will corrode while the copper will be protected.

If zinc is connected to iron and immersed in an aqueous solution, the zinc will corrode and protect the iron until the zinc becomes coated with zinc oxide, after which the action ceases.

It has been maintained that since *zinc oxide* is electro-negative to iron, the current will be reversed and the iron will corrode faster than if no zinc oxide were present, but this contention has not been sustained by experiment.

The temperature of such couples immersed in solution has an important bearing on the amount of corrosion which will occur, since the electrolytic potentials of metals and solutions, and the amount of oxygen in solution, vary also with the temperature. In general, the difference of potential between metal and solution will increase with the increase of temperature. The temperature at which maximum corrosion takes place is about 160° to 180° F.

The effect of acids on corrosion.—If an acid is present in the solution, the corrosive effect is increased, and the rate at which corrosion progresses under such circumstances depends directly upon acid strength of the solution.

It is worthy of note, however, that a piece of iron dipped in fuming nitric acid will resist corrosion for reasons which have not as yet been satisfactorily explained. This protection is only temporary, however, and has no practical application.

Corrosion of alloys.—The electrolytic potential of an alloy is different from that of any of its constituents, generally lying between them.

Bronze and brass alloys generally have a low potential and hence are not readily corroded by salt water. This makes naval bronze a good material for use on under-water fittings of ships, such as outboard delivery valves, etc.

The effect of sodium chloride.—Sodium chloride (NaCl), which is present in distilled sea water, has a marked effect on corrosion. By increasing the conductivity of the water the corrosion is accelerated. Where steel or iron is protected by being in metallic contact with zinc, the result of NaCl in solution is to increase the protective effect, and extend it over a greater area.

If boiler water is made *sufficiently* alkaline by the addition of soda, lime or other compounds, corrosion will be prevented. The necessary alkaline strength in distilled water free from NaCl has been found to be about 3%

of a normal solution. *When sodium chloride or other salts are present, a higher alkalinity will be necessary, depending on the amount of salt present in solution.*

The use of alkalies for this purpose is dangerous in one particular. Just before the point is reached at which corrosion is prevented, the rusting will be confined to a few spots and will take the form of *pitting*. If the alkalinity is never allowed to exceed 0.5%, however, pitting will not take place, and this alkalinity will insure that the water does not become acid.

Keeping the alkalinity at 0.5% will not prevent corrosion entirely if any oxygen is present in the water; but *pitting* will be prevented, and such corrosion as does occur will be general and not so dangerous to the safety of the boiler.

3. WATER TREATMENT

Reasons for treating boiler water.—There are three reasons for treating boiler water, viz.: (a) to render it as nearly noncorrosive as possible, (b) to prevent the formation of scale, (c) to prevent the rise of surface tension and consequent priming caused by the impurities in the water and by the application of the remedies for (a) and (b). *Surface tension* is the molecular action of a liquid which resists any force tending to break through the free surface. This causes priming in boilers by its resistance to the flow of the steam bubbles through the surface, and therefore the boiling action is more violent and particles of water are carried over with the steam.

Boiler compounds are mixtures of electrolytes, which, when dissolved in feed water, are claimed to fulfill the requirements given under (a), (b) and (c) in the preceding paragraph. There are many boiler compounds on the market of various degrees of merit; some of them are very good, but *all are injurious if used without the proper degree of intelligence.*

Experiments show that good homogeneous steel immersed in distilled water corrodes almost equally over its wetted surface. As the concentration (i.e., the percentage of normal alkaline solution) is increased by the addition of an electrolyte such as boiler compound, the *rate* of corrosion is at first slightly *decreased*, and after a certain concentration is reached, the rate of corrosion is *increased*. An *electrolyte* is a substance which increases the electrical conductivity of water when the substance is dissolved in the water. At a certain definite concentration the rate of corrosion reaches a maximum, and then falls off rapidly as the concentration increases, reaching a definite point at which corrosion ceases, *provided no salt is present in the water*. If any salt is present in the water, a higher concentration will be necessary before corrosion is prevented, *the concentra-*

tion necessary to prevent corrosion increasing with the amount of salt in solution.

It is evident, from this, that it is better to use no treatment than to use any chemical or compound without knowing, by test pieces, whether the water is actually corroding the boiler metals. The method of using such test pieces is described later in this chapter. There is also the danger that the saturation concentration will be reached and the chemical will be deposited as scale. This, however, is not probable with the Standard Navy Boiler Compound.

The following are some of the qualities required in any compound used in the treatment of boiler water :

(1) It must contain one or more metallic elements that have a higher electrolytic potential than the material of the boiler, preventing the metal from going into solution.

(2) It must contain some strong alkali to make the water alkaline at low concentrations.

(3) It must be incapable of being broken down into other compounds giving acid reactions within the range of temperature to which the boiler water is subjected.

(4) It must be soluble at these temperatures.

(5) It should not be conducive to priming by increasing surface tension.

(6) It should contain some chemical compound which will combine with any scale-forming elements and keep them in suspension as sludges.

The chemicals generally used are alkaline earth metals, due to their high solubility, high solution tension and low cost. *Solution tension* is a measure of the tendency of metals to dissolve when placed in aqueous solutions.

Navy boiler compound.—A boiler compound which, under tests, seems to be very satisfactory, was evolved at the Engineering Experiment Station, Annapolis, Md. It consists of (1) 95% calcined sodium carbonate (Na_2CO_3) ; (2) 4% di-sodium phosphate ($\text{Na}_2\text{HPO}_4, 12\text{H}_2\text{O}$) ; and (3) 1% of cutch or catechu. The first ingredient makes the solution non-corrosive, the second prevents priming and the third prevents formation of scale. The cutch is an organic compound containing 40% to 45% of tannic acid ; this has the property of preventing formation of scale, as it converts the foreign salts of the water from crystalline to colloidal state, and holds them in suspension within the range of boiler temperature. Starches and dextrans also have this property. The function of the di-sodium phosphate is to prevent the surface tension that causes foaming and priming. In addition, both sodium and potassium are very soluble and very high in the solution tension series. Distilled water was treated with the above compound and made non-corrosive ; the solution had 3% normal

alkaline strength. Evaporated to dryness, baked and treated with the original amount of distilled water, the compound all redissolved.

Impure water.—We will now take up the subject of impure water, the precipitates formed by the action of heat and the chemical action of the compounds used to render the water non-corrosive, and the treatment required to change these precipitates into their colloidal form and hold them in suspension in the solution.

Water appears in nature in two forms: (1) that of the ordinary state, (2) that of the water of crystallization in compounds precipitated from ordinary water solutions.

The purest water found in nature is rain water after it has rained for time; the first rain that falls absorbs the impurities in the air and is, therefore, impure.

As soon as rain water comes in contact with the earth and starts on its course to the sea, it begins to dissolve various substances according to the nature of the soil with which it comes in contact. Streams that flow over sandstone beds contain exceptionally pure waters, as sandstone is very insoluble. Those that flow over limestone beds dissolve some of the stone and the water becomes "hard." The many varieties of natural mineral waters are due to substances from the earth being dissolved in the water.

Distilled water.—All natural water is, therefore, more or less impure, and the impurities vary with the nature of the soil in the territory through which it has passed. In order to get pure water it must be distilled and kept free from air.

When pure distilled water is used in boilers, the treatment required is (1) an electrolyte to raise the potential of the solution and prevent the metal from dissolving, and (2) one to prevent the high surface tension that causes priming.

Natural water from limestone localities contains calcium acid carbonate in solution; when the water is heated this is converted to calcium carbonate (CaCO_3) and precipitated. At 300° F. it is practically all precipitated as a sludge, if the water contains no other impurities. If it contains calcium sulphate or magnesium carbonate or sulphate, it forms a hard scale. With the magnesium and calcium sulphates, as they are precipitated, calcium carbonate sludge acts as a binder, cementing them into hard scale. Water from localities containing magnesium compounds dissolves magnesium in the form of the acid carbonate and the sulphate. Magnesium carbonate precipitates as a magnesium hydroxide ($\text{Mg}(\text{OH})_2$), which is soluble only to about one-half grain per gallon. Magnesium sulphate (MgSO_4) is quite soluble at boiler temperatures, but in the presence of CaCO_3 it forms magnesium carbonate (MgCO_3) and calcium sulphate

(CaSO_4), both of which are only slightly soluble. In the presence of sodium chloride (NaCl) it forms very soluble sodium sulphate (Na_2SO_4) and magnesium chloride (MgCl_2).

Calcium sulphate is found in natural waters, and under ordinary conditions of temperature it is soluble to about 100 grains per United States gallon. Its solubility decreases with a rise in temperature, and at about 300°F . it is practically all precipitated.

Streams that flow through localities containing salt (NaCl) contain it in solution in comparatively large quantities.

Natural fresh waters have in them, as the principal impurities, carbonates, sulphates and chlorides in quantity in the order named. The principal carbonate is the acid carbonate of calcium $\text{Ca}(\text{HCO}_3)_2$, the principal sulphate is that of magnesium MgSO_4 , and the principal chloride is that of sodium NaCl . The metals calcium, magnesium and sodium are cations in electrolytic dissociation.

Sea water.—Sea water contains the impurities contained in the waters emptying into it and those absorbed from the soil of its bottom.

The average composition of the water of the oceans is about 3.5% salts and 96.5% water.

COMPOUNDS FOUND IN THE SEA WATER.

Salt—Sodium chloride	NaCl
Magnesium chloride	MgCl_2
Magnesium sulphate	MgSO_4
Magnesium bromide	MgBr_2
Potassium sulphate	K_2SO_4
Calcium sulphate	CaSO_4
Calcium carbonate	CaCO_3

COMPOSITION OF SALTS FOUND IN OCEAN WATER (ABOUT).

	<i>Per Cent</i>
NaCl	77.76
MgCl_2	10.88
MgSO_4	4.74
CaSO_4	3.60
K_2SO_4	2.46
CaCO_3	.34
MgBr_2	.22

The maximum percentage of salts found in sea water is 3.737%, the average percentage 3.5%. The mean density of sea water is 1.027.

The percentage of salts in sea water may range from 1 to 4, but the percentage of each salt has been found to remain practically constant.

The principal impurities in sea water are chlorides, sulphates and carbonates, in the order named. It may be seen that the order of the salts as

quantity in sea and natural fresh waters is just reversed. Sea water dissolves only 83% as much oxygen as does fresh or distilled water.

It is now seen that the scale forming ingredients in water, both natural fresh water and sea water, are the calcium sulphates, calcium carbonates and magnesium hydroxides. When sea water is treated with sodium carbonate, enough of it must be added to the water to precipitate all of the salts with which it will react, and then enough more to bring the normal alkaline strength of the solution up to a certain definite percentage. This percentage has been found to be about 2.5 for ordinary good steel boiler plate. The reactions that take place when treating sea water with sodium carbonate are as follows:

Mineral salts in sea water	Chemical with which sea water is treated	Compound formed that is insoluble within the range of temperatures of boiler water	Compounds formed that are incompletely soluble within the range of temperatures of boiler water until near the point of saturation
NaCl	Na_2CO_3		NaCl and Na_2CO_3
MgCl_2	Do.	MgCO_3	NaCl
MgSO_4	Do.	Do.	Na_2SO_4
CaSO_4	Do.	CaCO_3	Do.
K_2SO_4	Do.		K_2CO_3 Na_2SO_4
MgBr_2	Do.	MgCO_3	NaBr
CaCO_3	Do.	CaCO_3	Na_2CO_3

These insoluble salts are all precipitated at a temperature of 300° F. as calcium carbonates and magnesium hydroxide, the carbonate of the magnesium compound being transformed into carbonic acid gas and driven from the water as CO_2 at temperatures above the boiling point. These, then, are the compounds that must be converted into their colloidal states and prevented from forming hard scale on the heating surfaces. This is done by the catch in a boiler compound.

CHAPTER IX

NOTES ON BOILER DESIGN

33479 B.T.U. trans./hr. = 1

Definitions.—*Boiler horsepower.*—This is a measure of the total weight of steam which a definite amount of boiler heating surface will generate. The unit of boiler horsepower as defined by the American Society of Mechanical Engineers is "the equivalent evaporation of 34.5 pounds of dry steam from and at 212° F." The horsepower of a boiler is, in other words, its capacity. Manufacturers rate a boiler at some nominal horsepower, usually based on ten square feet of heating surface per horsepower. This, however, does not imply that the evaporation of 34.5 pounds of water from and at 212° F. with ten square feet of heating surface is the limit of the capacity of the boiler. Neither does it imply that a boiler is in a state of strain when developing more than its rated capacity.

Boiler efficiency.—This is the ratio of the heat absorbed by the steam generated to the heat available in the fuel burned.

Water rate.—The pounds of steam used per engine horsepower developed per hour.

Grate surface.—The grate area available in a boiler on which solid fuel can be burned.

Furnace volume.—The volume available in a boiler in which liquid fuel can be burned.

Heating surface.—The total surface available expressed in square feet through which the heat of combustion of fuel can be transferred to the water in the boiler.

Requirements.—Naval boilers must fulfill the following requirements:

(1) *They must be reliable, safe, and have adequate life.*

(2) *All parts must be accessible for cleaning and easy to repair.* This has become especially necessary in recent years when most of the maintenance and repair has been done by forces afloat. The design should permit of the rapid and easy removal of defective or injured parts.

(3) *Maximum capacity in square feet per ton of boiler, and with that reasonable efficiency.* The problem of design in these respects is especially difficult in naval practice, due to the exceedingly high rates demanded of express-type boilers and to the limitations of weight and space necessarily imposed.

(4) *Flexibility.* Naval boilers should be capable of a wide and rapid variation of load.

In general a boiler is divided into two parts: (a) that of *heat generation*, comprising the grate, combustion space, gas passages, and baffles; (b) that of *heat absorption*, including tubes, downcomers, headers, steam drums, etc.

The problem of heat generation, assuming proper walls and refractory materials, is concerned principally with (1) feed of fuel and feed of air and (2) proper mixing of the two. In other words, there must be a means for proportioning air and fuel and a means of maintaining this ratio at various rates. Proper design must cause the heat to be liberated in the proper place. The flow of hot gases must be positive and unimpeded and must reach all of the heating surfaces. Gas paths are usually controlled by baffles which must be so designed that there are no dead pockets.

The question of heat absorption is largely a matter of circulation. The circulatory forces must be strong and positive, avoiding any dead ends where the circulation is retarded or stopped entirely. The nearer the steam is generated toward the outlet of the tube, the better the circulation. The hottest gases should therefore be at the outlet of the tubes.

Efficiency.—The criterion by which the efficiency of a boiler installation is to be judged is, from a naval point of view, the weight of fuel used per unit weight of steam generated. Extended cruising radius and not particularly low cost of production of steam is what is desired. In other words economy in fuel is desired due to limited stowage space rather than reduction of cost of operation. The question of efficiency is largely a matter of proper relation between fuel, furnace, and boiler heating surface, together with proper supervision of operation. However, efficiency must be a compromise between the theoretically possible high efficiencies and the necessary departures from the theoretical design and operating conditions due to the practical considerations of reliability, flexibility, and simplicity of operation.

Capacity.—Capacity is the total weight of steam which a given amount of boiler heating surface will generate. Theoretically, the capacity of a boiler is limited only by the amount of fuel that can be burned under the boiler. However, other considerations enter such that it is inadvisable to attempt high capacities from small heating surfaces for the following reasons:

- (a) Lack of space on naval vessels prohibits increase of furnace volume.
- (b) The efficiency, in general, decreases with an increase of capacity over that designed.
- (c) Priming may result at high rates if circulation is not positive.

Effect on efficiency of varying capacity.—The results of tests show that the rate of heat transfer does not increase proportionately with an

increased weight of hot gas. So, presupposing a constant furnace temperature, the higher the rate of evaporation, the higher the exit temperature of the gases. This indicates that a smaller percentage of heat is absorbed and a lower efficiency results. Furthermore, a part of the heat absorbed is by radiation, the amount of which depends solely on the amount of heating surface. Therefore, for constant furnace temperatures, the heat absorbed by radiation does not increase as the weight of gases increases. This factor also tends to decrease efficiency with increased capacity.

General discussion.—Having designed a boiler which fulfills the general requirements, the question of boiler installation in the ship is next considered. This is done generally in the following manner: When general characteristics of the ship have been determined, a bare hull model is constructed to dimensions. This model is towed in a model basin at various speeds and from these experiments an "effective horsepower" curve is constructed under the direction of the Bureau of Construction and Repair.

These data are then forwarded to the Bureau of Engineering where the type of propelling machinery and propeller is decided upon. A propeller efficiency based on former experience and improvements in design is assumed; these efficiencies vary from 50 to 60 per cent. From the propeller efficiency and other data, a propulsive coefficient is obtained. The propulsive coefficient at maximum speed is the ratio of the effective horsepower necessary to pull the bare hull through the water to the total engine horsepower necessary for the engines or turbines to drive the vessel through the water at the same speed under the same conditions. Therefore the total engine horsepower is obtained by dividing the effective horsepower by the propulsive coefficient. The total horsepower of the steam-driven auxiliary machinery is then computed.

A water rate for the main engines at maximum power and the auxiliaries is assumed, sufficiently high above the contractor's guarantees to insure sufficient steam and still have a reserve. The total engine horsepower multiplied by the assumed water rate gives the total number of pounds of steam required per hour. Assuming a rate of evaporation per square foot of heating surface, the total heating surface can then be determined. Total Engine H.P. $\times$ Water Rate = No. Pounds Steam Required.

It is then necessary to select a certain design of boiler such that the total number of boilers necessary to generate the requisite steam can be located in the compartments available, be below the protective deck, and have sufficient space around each boiler that it may be properly worked.

Design notes.—The following figures and methods of calculation used in boiler design are, for the most part, the result of previous experience

rather than pure mathematical calculation, and are tabulated here more to give the student an idea of actual figures than to represent the latest practice.

Water rate.—The water rate of the main engines at maximum and fractional powers is laid down in the Navy Department specifications, and must be met by the contractor. Typical water ratio is as follows:

Battleship (reciprocating engines)	—19
“ (turbine)	—18
“ (electric drive)	—12.5
Destroyer (geared turbine)	—15
Light cruiser (geared turbine)	—14.5

Capacity.—Conservative estimates give 9 pounds of water evaporated from and at 212° F. per square foot of heating surface. However, ratios of evaporation up to 22.73 pounds for an express-type boiler have been obtained.

Grate surface and furnace volume.—In a coal burning boiler, the grate surface is calculated from the heating surface. This ratio in some designs is 1 to 44.5, grate to heating surface. In oil fired boilers the ratio between cubic feet furnace volume and square feet heating surface varies between 1:8.6 and 1:14.4.

Air supply.—The total area between the grate bars in the furnace of a coal-burning boiler must be sufficient to pass 250 cubic feet of air per hour at a velocity of 30 feet per second through the fire for each pound of coal burned. The openings through the cone brick of an oil-burning boiler must be large enough to pass into the furnace 300 cubic feet of air for each pound of oil burned per hour, when the air is under the designed maximum draft pressure.

Gas passages.—The area around the tubes of a water-tube boiler for the gases of combustion should equal 0.143 times the grate area or 0.0032 times the heating surface. The same figures apply to the uptakes and cross-sectional area of smoke pipe.

Strength calculations.—The thickness of tubes, drums, headers, and nipples for water-tube boilers are calculated for the maximum test pressure by rules for thin cylinders found in any textbook on machine design.

Steam piping.—The diameter of the main steam piping and branches are calculated for a mean velocity of steam from 6,000 to 7,000 feet per minute. Knowing the pressure and density of the steam and the quantity that each branch is to deliver, the cross-sectional area, and therefore the diameter of the pipe are easily calculated. The branches to the boilers should be arranged so that each boiler will supply its full quota of steam to the main steam line at the same pressure as any other one.

Feed piping.—Knowing the quantity of water to be delivered to each boiler and its velocity, the feed lines are calculated in the same manner as the steam piping. A velocity of from 300 to 400 feet per minute is assumed, from which the diameter of the main feed line and its branches to the boilers are calculated, so that each boiler will get its proper quota of water.

The area of the openings through the valves in the main steam and feed lines is always slightly greater when the valves are wide open than the area of the opening through the pipes to which they are attached.

Pipe thicknesses.—The thicknesses of all pipes are calculated by the following formulas:

$$\text{For straight copper pipe, } T = \frac{P \times D}{8,000} + \frac{1''}{16}.$$

$$\text{For steel pipe, } T = \frac{P \times D}{10,000} + \frac{1''}{16}.$$

where P = pressure above the atmosphere in pounds per square inch.

D = inside diameter of pipe in inches.

T = thickness of pipe in inches.

Materials.—In the construction of naval boilers, the following materials are used:

Welded or flanged plates.—Class B open hearth steel.

Other plates.—Class A or B open hearth steel.

Rivets.—Class A or B open hearth steel, in conformity with the class of plates that are connected by them.

All pressure parts are constructed entirely of open hearth steel plate.

No malleable or cast-iron parts shall be subjected to pressure.

No screw joints are allowed in contact with the fire.

Boiler tubes are made from cold drawn seamless steel. The thickness of the tubes are generally given in Birmingham Wire Gage units.

CHAPTER X

MEASURING INSTRUMENTS

1. FOR MEASURING STEAM

Steam calorimeters.—Calorimeters are used for measuring the amount of moisture in the steam; from that measurement the quality is determined. There are three general classes in common use: (1) the *super-heating or throttling*; (2) the *separating*; and (3) the *condensing* calorimeters.

One type of superheating and one of separating calorimeters will be described.

Carpenter's throttling calorimeter.—Fig. X-1 shows Professor Carpenter's throttling calorimeter. It consists of a small vessel *A*, to which steam is supplied through a stop valve and converging nozzle *B*. The vessel contains in its center a very deep cup, into which a thermometer is inserted for determining the temperature of the steam in the calorimeter. A cock *C* connects to a mercury filled manometer for measuring the pressure of the steam in the calorimeter. The exhaust steam is discharged from the lower part of the calorimeter and is permitted to escape freely.

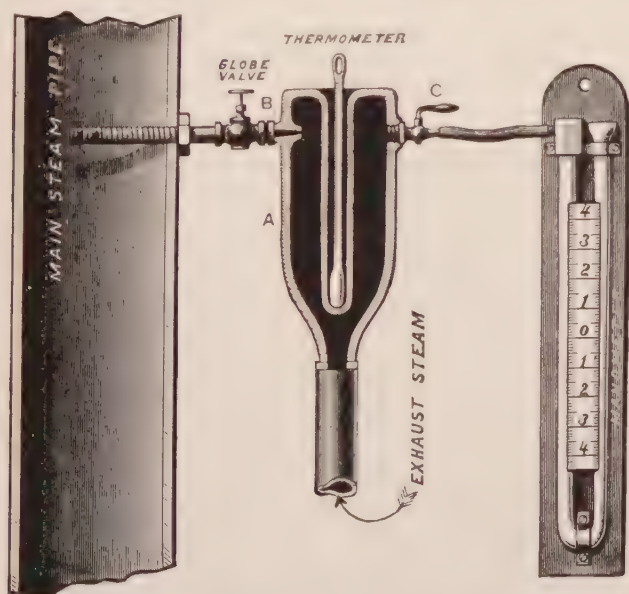


FIG. X-1.—Carpenter's Throttling Calorimeter.

The velocity is wholly reconverted to heat and since no work is performed the total amount of heat remains constant. Inspection of the total heat-entropy (Molliere) diagram shows that if the total heat remains constant while the pressure decreases, the steam becomes drier and is finally superheated. The process is represented on the diagram by a horizontal line drawn from left to right.

To determine the quantity of moisture in the steam the pressure is measured in the steam pipe, the pressure of the manometer and the temperature indicated by the calorimeter thermometer are observed. Then if the amount of expansion is sufficient to produce superheat at the exhaust

$$h + xL = H + k(t_c - t)$$

where the left side of the equation indicates the total heat of the steam in the pipe and the right side the total heat at the outlet.

h = heat of liquid above 32° F.

x = quality of steam.

L = latent heat of evaporation.

H = total heat of steam above 32° F.

k = specific heat of superheated steam.

t_c = temperature of calorimeter.

t = temperature corresponding to pressure of calorimeter.

The values of h and L are taken from the steam table corresponding to the pressure in the steam pipe. The values of H and t are taken from the steam table corresponding to the pressure in the calorimeter as read from the manometer. An average value for k is 0.48. Substituting these values in equation (1) and solving for x the quality of the steam may be found.

Limitations of throttling calorimeter.—If the percentage of moisture is so great that the steam, expanding into the calorimeter, does not become completely dried, the instrument is of no value. The theoretical limit is found for any initial temperature t_1 by putting $t_c = t$ in equation (1). The practical limit is somewhat lower, and varies from 2.3 per cent of moisture at 50 pounds boiler pressure to about 7 per cent at 300 pounds.

The range of the instrument can be increased by connecting the exhaust to a condenser. Thus, with a vacuum of 28 inches and a steam pressure of 50 pounds gage, the limit percentage of moisture would be about 8 per cent.

For small percentages of moisture the throttling calorimeter is the handiest and most accurate form of apparatus. The sampling nozzle of this instrument must extend almost across the steam pipes and have a sufficient number of small holes in it to insure its getting an average sample of the steam. To obtain reliable readings, the calorimeter should be thoroughly warmed up; and if readings are taken at frequent intervals, steam should be blown through continuously. The calorimeter and the connection to the steam pipe must be well lagged to prevent loss of heat by radiation.

Carpenter's improved separating calorimeter, shown in Fig. X-2, contains two vessels, one inside the other. The outer surrounds the inner, leaving a space which serves as a steam jacket. The inner vessel is provided with a glass water gage 10 and scale 12.

The steam under test is admitted through pipe 6, striking the bottom of a perforated cup 14, and is deflected nearly 180°. The water is thrown off and passes through the perforations into the inner vessel 3, where the amount is indicated by the graduated scale 12 on the gage glass 10. The steam passes across the top of the perforated cup and into the outside chamber, from which it is discharged through a small orifice 8, of known area, in the bottom part. The orifice 8 is so small in comparison with any section of the steam pipe or throttle valve that there is no sensible reduction in pressure by passing through the calorimeter. The pressure in the outer chamber being the same as that in the inner, it has the same temperature, and consequently there is no loss by radiation from the interior surface except that which takes place from the exposed surface of the gage glass.

It has been demonstrated that the flow of steam through a small orifice is proportional to the absolute steam pressure, until the pressure against which the flow takes place equals or exceeds 0.6 of that in the vessel under pressure. A special form of steam gage is

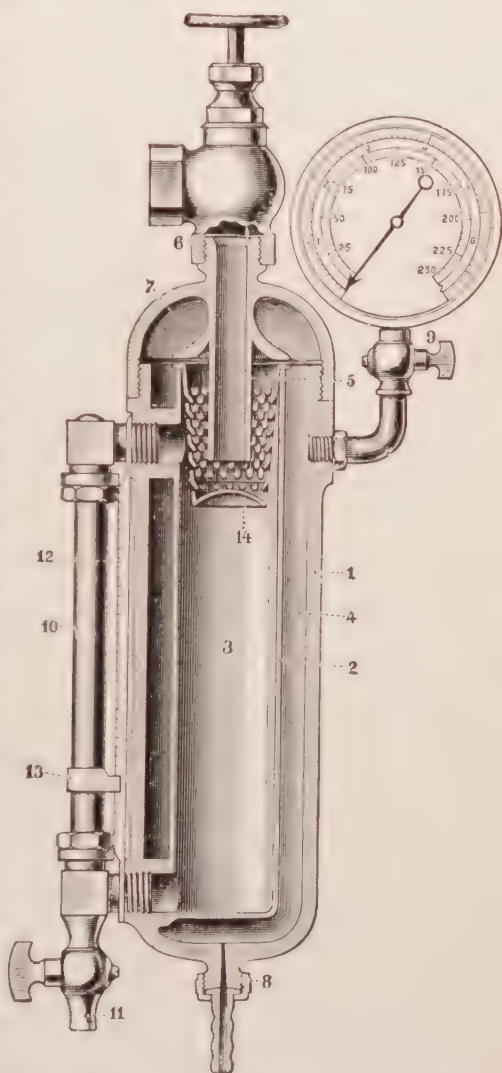


FIG. X-2.—Carpenter's Improved Separating Calorimeter.

placed on the outer chamber, the inner circle of which shows the gage pressure, while the outer circle shows the number of pounds of steam that will escape through the orifice in ten minutes of time.

The scale 12 is graduated to hundredths of a pound, and shows the weight of water contained in the inner vessel. The instrument is operated at a constant pressure for ten minutes, and w , the weight of water collected, is read off; also W , the weight of dry steam that escapes through the orifice, is read off on the outer circle of the steam gage. Then

$$x = \frac{W}{W+w}, \text{ and } 1 - x = \frac{w}{W+w}.$$

The separating calorimeter is accurate and applicable in all cases where the steam contains moisture. It is not applicable with superheated steam.

The sampling nozzle in the steam pipe must be fitted to get an average sample of the steam, and the instrument and its connections must be well lagged.

Steam flow meters.—Steam flow meters while not installed on naval vessels are used at the U. S. Naval Experiment Station, Annapolis, Md., and the Fuel Oil Testing Plant, Philadelphia, Pa., also in many shore power plants. They indicate the number of pounds of steam per hour, minute, or second as desired passing through a steam line. Integrating recorders giving the number of pounds of steam passing through the line in any period of time are usually furnished with them. There are two uses for steam flow meters on boilers, the first of which is to insure that all boilers are carrying the same load and the second is in order to enable the fireman to see that more or less steam is being used without having to be notified or waiting until the pressure gage rises or falls. The first use is desirable with coal burning boilers where some boilers may be fired more efficiently than others, thus indicating which boiler's firing methods should be remedied. With oil burning boilers using the same number and size of burners, air and oil pressure, the conditions of the boilers as to cleanliness and leaks would be indicated. Steam flow meters based on the principle of deflection of indicators from certain positions would not be practical aboard ship on account of the motion. Orifice plates or Venturi tubes installed in the pipes with manometers, either electrical or mechanical, are the essential parts of steam flow meters.

Feed water meters are sometimes installed in the feed lines to boilers in connection with the steam flow meters in order to determine if there are any leaks from blow-down valves, etc.

2. FOR MEASURING FLUE GASES

Thermometers.—Ordinary glass mercurial thermometers are used for measuring temperatures of feed water, saturated steam, and air when these temperatures are not higher than 500° F.

Thermometers are placed in so-called *thermometer wells*, which screw through the container casing and extend well into the current of gas or liquid to be measured. The bottom of the well should be filled with mercury or mineral oil of high boiling point. The thermometer should be inserted into the well so that only a few degrees on the stem below the expected mean temperature should be visible. This obviates the necessity for a stem correction.

Stem correction.—If the stem of the thermometer is not submerged to the height of the mercury, a stem correction must be made to compensate for the difference in expansion of the glass and the mercury.

A second thermometer is secured by pieces of string or wire to the one on which the readings are taken; and the bulb of the second thermometer is wrapped with waste, in order that it may show the temperature of the stem to which it is attached. The correction to be applied to the reading of the first thermometer is given by the formula:

$$\text{Stem correction} = .000088 u(T-t),$$

where u = number of degrees projecting from liquid,

T = reading of immersed thermometer in degrees F.,

t = reading of auxiliary (second) thermometer in degrees F.

This correction is always positive.

Pyrometers.—For temperatures above 500° F., pyrometers must be used. These are of several forms, as (1) *pneumatic*, (2) *mercurial*, (3) *expansion*, (4) *calorimetric*, (5) *thermo-electric*, (6) *resistance*, and (7) *reflecting*.

Many shore plants use electrical recording pyrometers to keep a check on the temperature of flue gases.

Le Chatelier's pyrometer.—This is a most reliable instrument for measuring high temperatures. It consists of a thermo-element composed of a platinum wire and another of an alloy of platinum and rhodium. The wires are insulated by a thin porcelain tube, and the junction is protected from the gases by a larger, closed porcelain tube. The current of electricity, generated by exposing the junction to heat, is measured by a suitable galvanometer, which has a carefully calibrated temperature scale besides the voltage scale. The junction of the thermo-couple is in the form of a small ball or button.

Fig. X-3 shows an improved form of this instrument devised by the

Vulcan Manufacturing Company, of Pittsburgh. This form was designed for use in ascertaining the temperatures of molten metal, for which purpose the porcelain tubes would not answer. Even with the ordinary measurements of the gases of combustion, the porcelain tubes have to be handled with great care to prevent breaking.

An iron tube, through which run the wires of the couple, has a connection at one end for the clay tip which protects the junction, and, at the other end, a terminal box for the copper wire connections to the galvanometer. The wires are covered with asbestos for insulation from each other and from the iron pipe, and are covered by an asbestos tube where they pass through the fire-clay tip. The connection for this tip is inter-

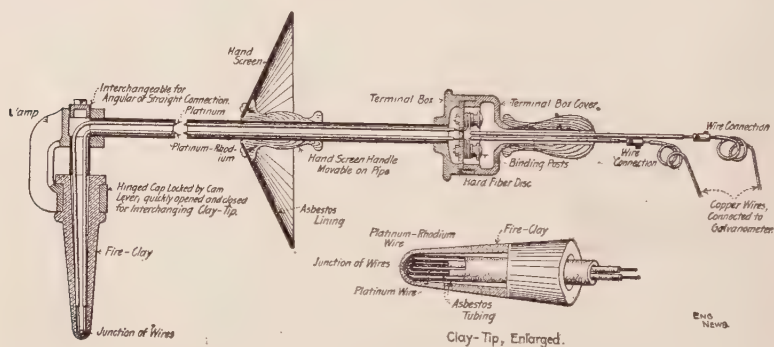


FIG. X-3.—La Chatelier's Pyrometer.

changeable, so that the tip may be secured at an angle, as in the figure, or straight. The rest of the instrument is fully explained by the figure.

The galvanometer used is a D'Arsonval, specially made and calibrated for industrial purposes, the original form, with a reflecting mirror, and capable of registering to 0.5° , being too cumbersome and delicate. The sensitiveness of the couple, even when protected by a refractory material is such that, when it is plunged cold into the melted iron, the reading is obtained in 1.75 minutes. When it is heated to redness beforehand, this time is reduced to a few seconds.

An automatic recording device is sometimes added.

Gas-analysis outfit.—The chemical outfits are constructed on the Orsatt principle of measuring the volume of a gaseous mixture, treating it with a chemical that absorbs one of the constituents, and then, when the volume is remeasured, calculating the percentage volume of the absorbed constituents from the difference in the first and second volumetric measurements. The percentage volume of any absorbable gas constituent can be

determined by use of the analysis outfits, but their principal use in the Navy occurs in the analysis of the gases of combustion, carbon dioxide (CO_2), oxygen (O), and carbon monoxide (CO).

The gases are drawn through a sampling pipe in the boiler. Since the combustion of the gases has not been completed in the lower part of the furnace and as all useful combustion has occurred by the time the gases have arrived at the last row of tubes in the last pass of the boiler, it is here that the sample should be drawn. Gases drawn from the uptakes or near the side of the boiler are likely to be mixed with air.

In collecting gases for examination, care must be taken that the sampling pipe reaches to the middle of the gas current in the center of the boiler in order to obtain an average sample. The sampling pipe is not perforated but the end in the boiler is left open.

Several kinds of chemical gas-analysis outfits have been used among which are the Elliott, Orsatt-Muencke, Hays, and Williams. They are all based on the Orsatt principle and therefore the method of making the tests are similar although the manner of obtaining the samples differ. For oil burning boilers with clean, properly operated burners, a light brown haze indicates efficient combustion as determined by gas-analysis tests. With coal burning boilers efficient combustion without gas-analysis tests is purely a hit-or-miss proposition. For oil burning boilers "grab" samples are obtained while with coal burning boilers an average sample is required on account of the different conditions of the fires. An average sample may be obtained by filling the sample collecting tank with water, allowing it to run out slowly, the water being replaced by the gases from the collecting pipe leading into the boiler. Once the correct method of firing a particular kind of coal has been determined by use of a gas-analysis outfit, the correct level of the fuel bed may be maintained by readings of a draft gage.

There are several automatic CO_2 indicators with recorders on the market although those tried out afloat have proved unsuccessful. Some of them automatically test the gases with chemicals similar to the CO_2 absorbent in the chemical gas-analysis outfits. Others are based on the principle that the weight of flue gases increase in proportion to their CO_2 content, CO_2 being about 50 per cent heavier than the other constituents of the flue gases. The latter are called mechanical indicators. Still others are based on the principle of the chemical reaction of electricity on gases. Because of different conditions of the fires in coal burning boilers a graphical recording instrument is necessary in order to obtain the average CO_2 content, while with oil burning boilers an indicator is all that is necessary except for purposes of record.

A book of detailed instruction is furnished with each apparatus.

Orsatt-Muencke apparatus.—The Orsatt-Muencke apparatus, shown in Fig. X-4, is one in which the three reagents are carried in separate pipettes *A*, *A'*, and *A''*. *B* is the graduated burette connected to leveling bottle *K* by a rubber hose, and surrounded by a water jacket. The reagents, instead of being put into one tube successively, are kept in separate treating pipettes, *A*, *A'*, *A''*. These are U-shaped, with one end of each connected by rubber tubing and a stop cock to the pipe which supplies the gas to *B* from *F*. The other ends of *A'* and *A''* are connected to two siphon bottles, forming a water seal to prevent air from the atmosphere from getting to the reagents. These siphon bottles (not shown) and the other end of *A* are open to the atmosphere. To increase the absorbing surface of the reagents, the pipettes are filled with glass tubes.

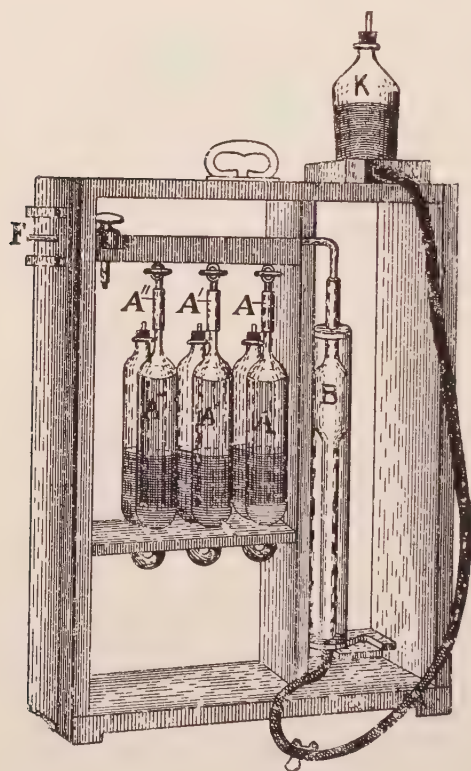


FIG. X-4.—Orsatt-Muencke Apparatus.

In the analysis of gases of combustion, the constituents must be taken in the order CO_2 , O, and CO, as the absorption liquid for CO will take in solution some of the oxygen, and that for oxygen will take in solution some of the CO_2 .

The absorbents are. (1) for CO_2 potassic hydrate, prepared by dissolving 1 part (by weight) of caustic potash (commercial stick form) in 2 parts distilled water (by weight); (2) for free oxygen, potassic pyrogallate, prepared by mixing together 5 grams pyrogallic acid in 15 cc. distilled water and 180 grams of caustic potash (commercial stick form) which has been dissolved in 80 cc. of distilled water,* (3) for CO, two absorbents are in use: (a) cuprous chloride solution in HCl,

* The oxygen should be measured at a temperature higher than 60°F . Pyrogallic acid, a white powder, comes in a dark bottle or dark wrapper and is affected by light. The pyrogallate solution should be kept in a dark bottle, tightly stoppered.

prepared by saturating distilled water with cuprous chloride and adding an equal volume of concentrated HCl, or $\frac{1}{2}$ (b) ammoniacal cuprous chloride, prepared as follows: (x) 200 grams commercial cuprous chloride are shaken in a closed flask with a solution of ammonium chloride (250 grams ammonium chloride in 750 cc. distilled water); (y) to every three volumes of this mixture 1 volume of ammonia (sp. gr. 0.91) is added. (x) and (y) are kept separate, and are mixed when needed; if kept mixed, a clean copper wire must be kept in the bottle. The absorption values per cc. of the reagents are about: (1) 40 cc. of CO_2 , (2) 22 cc. of O, (3a) 6 cc. of CO, and (3b) 16 cc. of CO.

The reagent for CO_2 is in the pipette *A* nearest the measuring tube, that for O in *A'*, and that for CO in *A''*.

In beginning an analysis, the reagents must be adjusted in the capillary tubes so that the level will be at a mark at the top of the pipette near the rubber connector. After the apparatus has been connected to the aspirator, and the leveling bottle has been filled with water, draw enough gas into the measuring tube to fill it, by lowering the bottle and opening the top pipe to the aspirator connection. This gas is then discharged by raising the bottle, the apparatus and connections thus being cleared of air.

Now draw in 100 cc. of the gas, observing the same precautions in measuring as given above. Then open the cock on the first pipette, and allow the reagent in it to absorb the carbon dioxide, by running the gas in and out of the pipette about four times. At the last time, the reagent must be allowed to fill the leg next to the measuring tube up to the mark. A rubber bag is usually provided for the purpose of causing alternate suction and pressure in the open end of the pipette, and to keep the air from the reagent. In order to be sure that the absorption of CO_2 is complete, the test should be repeated until the last two readings agree within 0.1 per cent. The same must be done with the tests for O and CO, except that in the last case the readings must agree exactly.

After the absorption of CO_2 , and the return of the remaining volume of gas to the measuring tube, wait one minute before taking the reading, in order to let the water from the sides of the tube drain down. Owing to the water jacket on the measuring tube, two menisci will appear when looking at the scale. So long as the same meniscus is read for the whole analysis, no difference will be made. It is best to read the bottom of a meniscus always.

The operation is next repeated for the absorption of the O, and then for the CO, each requiring a longer time than the preceding one. The reduction in volume each time is, as before, the percentage of the particular gas in the mixture as drawn from the smoke-pipe, the remainder, after

† Used by Bureau of Mines.

those gases have been absorbed, being classed as nitrogen. When transferring the gas during these operations, do not let the reagents, especially the caustic potash or pyrogallate, get into the measuring tube, as the water in the bottle must then be changed. Should a little water be allowed to get into the treating pipettes during a transfer, it will do no harm. About twenty minutes are required for an analysis by an expert with one apparatus. If two are used, two analyses may be made in twenty-five minutes.

B is graduated to read in percentage of volume. The reason for not graduating the burette to over 21 per cent is that, in the principal use of this apparatus, analysis of gases of combustion, the sum of the percentage volumes of CO_2 , O , and CO never amounts to over 21 per cent of the whole volume.

All readings should be made on the bottom of the meniscus, or curve of water, in the burette; it is essential to have *K* open, and to have the eye in the same horizontal plane with the water level in *K* and in *B*.

Suppose, for instance, that the analysis was started with the gas mixture filling the burette. If after the absorption of gas, the water in *K* and *B* balances, say at 12, then 12 per cent of the original volume was absorbed. If another constituent of the same gas is now absorbed and the second reading is, say, 16, then the second gas absorbed occupied $16 - 12$ or 4 per cent of the original volume. Suppose a third constituent is now absorbed and the reading at completion of the absorption is 17.5, then the third constituent occupied $17.5 - 16 = 1.5$ per cent of the original volume.

Air-pressure, or draft gage, or manometer.—The usual method of measuring the air pressure, or the draft, is by the difference in level of the water contained in the two legs of a glass U-tube, one end of which is open to the atmosphere and the other to the fireroom or air duct under pressure.

Fig. X-5 shows the ordinary air-pressure gage, without its case. The top of leg *A* is led to the atmosphere when this gage is used with the closed fireroom system, *B* being open to the fireroom. When the closed ash-pit system is used, *A* connected to the air duct near the ash pit, *B* being then open to the atmosphere in the fireroom. Scale *C* is graduated in fractions of an inch to represent the difference of level or pressure, the zero mark being in the middle of its length or height. When there is no pressure, the water level should be at zero. If it is not, water should be added or taken out in order to facilitate the

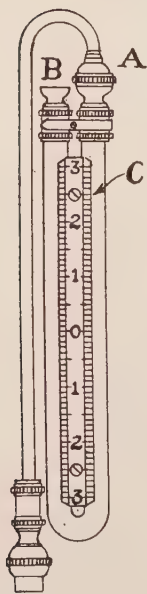


FIG. X-5.

reading of the scale. It will be readily understood that a pressure exerted on the water level in *B*, which will force it down 1 inch, will raise the level in *A* 1 inch, and that the pressure is equal to that of a column of water 2 inches high. This is, therefore, the air pressure in the fireroom or air duct.

The scale may be more conveniently arranged for reading by adopting a sliding scale, graduated from zero up. When a difference in the two legs is shown, the zero of the scale is put opposite the lower level, and the reading of the air pressure is taken from the higher level. No attention need then be paid to the quantity of water in the **U**-tube.

As the air pressure is frequently given in ounces (per square inch), it will be well to show the relation between inches and ounces.

A cubic foot of fresh water at 62° F. weighs 62.355 pounds; or a column of water 1,728 inches high and having an area of 1 square inch will weigh the same, or, in other words, will exert a pressure of 62.355 pounds per square inch. Therefore, 1 pound per square inch would be exerted by a column $1,728 \div 62.355 = 27.712$ inches high, or 1 ounce per square inch would be exerted by a column of water 1.732 inches high. Taking the reciprocal of this, 1 inch of water column is equal to a pressure of 0.577 ounce per square inch.

Smoke observations.—In order to have a uniform system of determining and recording the density of smoke produced, the smoke chart invented by Professor Ringlemann is now used. There are six cards, four ruled into small squares by lines of varying thickness, one entirely white, another solid black. They are numbered from 0 to 5, and are hung in a horizontal row about 50 feet from the observer and, as nearly as is convenient, in line with the top of the smoke pipe. At this distance, the lines on the ruled cards are not visible, and the cards appear to be of different shades of gray, ranging from very light gray to almost black. The observer glances from the smoke to the card and determines which one is nearest in color to that of the smoke. The number of the card and the time are then recorded. The observations should be frequent. The whole number of observations may then be plotted on cross-section paper, to show the variation in the smoke from time to time; and the average of all the records is taken as the average density for the test.

The ruled cards have usually seventeen horizontal and ten vertical lines, spaced ten mm. apart between centers. The thickness of the lines is 1, 2.3, 3.7, and 5.5 mm. for cards Nos. 2, 3, 4, and 5, respectively, the white spaces left between the lines decreasing, therefore, from 9 to 4.5 mm. square.

Deductions from results of gas analysis.—This analysis takes into account and measures the volumes of the dry gases. If the combustion

were perfect and were accomplished with the exact amount of oxygen to provide for the chemical combination of the constituents of the fuel, the smoke-pipe gas analysis would show only CO_2 , and nitrogen (by difference). The H_2O or steam gas would not be measured.

To obtain perfect combustion of any fuel, it is required that excess oxygen above the theoretical amount be supplied; in practice, when combustion is as nearly perfect as possible, the analysis of the gases of combustion always shows CO_2 , O, and N.

When the percentage of O in the analysis is less than about four, CO is found, indicating incomplete combustion due to insufficient excess of oxygen. This may be on account of the fires being too heavy, or the draft being too light, or both.

When the analysis shows over eight per cent of oxygen, it is found by practice that the excess of O is too great, on account of the fires being too light, or the draft being too heavy, or both, with a consequent loss of heat, due to the excess of air that has to be heated.

The presence of CO in the smoke pipe gases indicates imperfect combustion and a consequent loss of heat. Each one per cent of CO found indicates a loss of about five per cent of the heating value of good steaming coal.

CO and O appearing together indicate that the air and combustible gases are not properly mixed, or that they are chilled below the ignition temperature by the heating surfaces of the boiler before they are completely burned.

A high percentage of CO_2 , four per cent to eight per cent O, and any CO indicates that the rate of combustion of that fuel in that boiler is too high and the combustible gases and oxygen are chilled before they are all burned.

High percentages of CO and CO_2 in the same sample are never realized.

The percentage of N is found by taking $100 - (\text{CO}_2 + \text{CO} + \text{O})$.

Where carbon is completely burned to CO_2 , either with or without excess of air, the sum of CO_2 and O should equal 20.9 per cent, and the N should equal 79.1 per cent. (See composition of air.) Carbon burned to CO only, without excess of air, would give a gas containing 34.5 per cent CO and 65.5 per cent N. Hydrogen burned in the air without excess would give a gas 100 per cent N.

If the sum of the percentages of CO_2 , CO, and O is less than 19, the analysis must be looked on with suspicion.

For oil-burning boilers 15 per cent CO_2 with no CO indicates that the oil is being burned with maximum efficiency. Any smaller amount of CO_2 indicates excess air and consequent loss of efficiency.

However, it is better to have excess air and low CO_2 than have more than 0.5 per cent CO. For coal-burning boilers 14 per cent CO_2 is about as high CO_2 content as can be attained.

3. FOR MEASURING FUEL

TESTS OF COAL, PROXIMATE ANALYSIS

For moisture.—A portion of the sample is accurately weighed into an oven and dried for one hour at a temperature of 105° F. The sample is then removed and reweighed. The difference gives the percentage of moisture.

For volatile matter.—A portion of the dry coal should be weighed into a flask and heated to incandescence for fifteen minutes. This drives off the volatile combustible matter. The sample is then removed and reweighed; the difference, compared with the total weight of the original sample, gives the percentage of volatile matter.

For ash.—The remainder of the sample, after the moisture and volatile matter have been driven off, is then weighed on a platinum dish, and then heated in the open air until all of the combustible matter is burned. The weight of the residue, compared with that of the original sample used, gives the percentage of ash. This is the net value of the ash, and is lower than it is possible to obtain in burning the coal on a grate. In practice, the ash is generally 50 per cent greater than this.

The fixed carbon.—The fixed carbon is the difference between the weight of the original sample and the sum of the percentages of moisture, volatile matter, and ash. It requires a chemist to make a chemical analysis of the fuel, in which the percentage of each of the constituents is obtained.

Sampling.—In sampling coal for a test, the object is to obtain a small portion of the coal which represents as nearly as possible the entire lot of coal under test. Small shovelfuls of the coal should be taken from many parts of the pile, car, or barge, care being taken to get about the same number of shovelfuls from the top, middle, and bottom of the pile. The sample should contain as nearly as possible the same percentages of lump and fine coal as exist in the whole pile under consideration. This sample is then broken up into small particles by crushing, or with a maul, and the whole is thoroughly mixed into a conical pile. The pile is then quartered. Two opposite quarters are then taken, the remaining two being rejected. The two taken are then mixed and quartered. This process is continued until the lumps are one-fourth inch in size or smaller, and a 1- or 2-quart sample remains. This sample is then hermetically sealed in glass or metal jars and plainly labeled. Before the jar is sealed, the identification record of the coal should be placed in the jar.

Fuel-testing outfit.—In obtaining the heating value of fuels, both solid and liquid, Mahler's fuel calorimeter is in very general use. This instrument is the best known of the bomb calorimeters, in which a sample

of the fuel under test is burned in a bomb immersed in water and the amount of the heat of combustion is measured by the rise in temperature of the water.

Principle, description, and operation.—The combustible is placed in a closed bomb, made strong enough to resist heavy pressure, and filled with oxygen under pressure. The bomb is immersed in the water of the calorimeter, and the combustion is started by an electric ignition device. Because of the large quantity of oxygen in the bomb, the combustible burns completely and almost instantaneously. The products of combustion are confined in the bomb, and the heat is given off to the water and to the various parts of the instrument. Such losses as occur are easily estimated, and, owing to the rapidity of the combustion, most of the corrections become negligible.

The apparatus is shown in Fig. X-6, and consists of the following parts: *A*, water jacket; *B*, bomb of enameled steel; *C*, platinum tray for holding the fuel; *D*, the calorimeter; *E*, an electrode; *F*, a piece of fine iron wire for priming; *G*, the support for the agitator; *K*, mechanism for agitator; *L*, the lever for operating; *M*, a pressure gage for oxygen; *O*, flask of oxygen; *P*, an electric battery; *S*, the agitator; *T*, a thermometer; and *Z*, a clamp for holding the bomb while removing or replacing the cap.

The bomb is of the best quality of forged steel, with walls 8 mm. in thickness and a capacity of about 650 cc. The capacity is such as to assure perfect combustion of the fuel by a considerable excess of oxygen. This bomb is used also for experiments with gas and gas mixtures.

The bomb is nickel-plated on the outside and enameled on the inside to protect it from attack by the nitric acid always formed during combustion. It is closed by a cap screwed down on a lead gasket. This cap has a valve in its center with a screwed nozzle for connecting to the oxygen flask, and is pierced by a well-insulated platinum electrode, which is prolonged on the inside by a platinum rod *E*. A second platinum rod, fixed to the cap, sustains the platinum tray *C*, which carries the sample of fuel under test. A spiral of very fine iron wire connects *C* with *E* and comes in contact with the fuel when the bomb is charged. When the current is turned on, this wire is heated to redness and then burns in the atmosphere of oxygen, igniting the fuel. The agitator, consisting of vanes, carried on a central rod with a spiral thread passing through a fixed nut, is operated by a lever, which permits the operator to stir the water in the calorimeter systematically, thus assuring an even temperature. The valve on the flask does not have a fine enough adjustment to permit the gradual introduction of the oxygen; hence, a second valve (not shown in the figure) having a very fine adjustment is placed in the connection to the tank for this purpose.

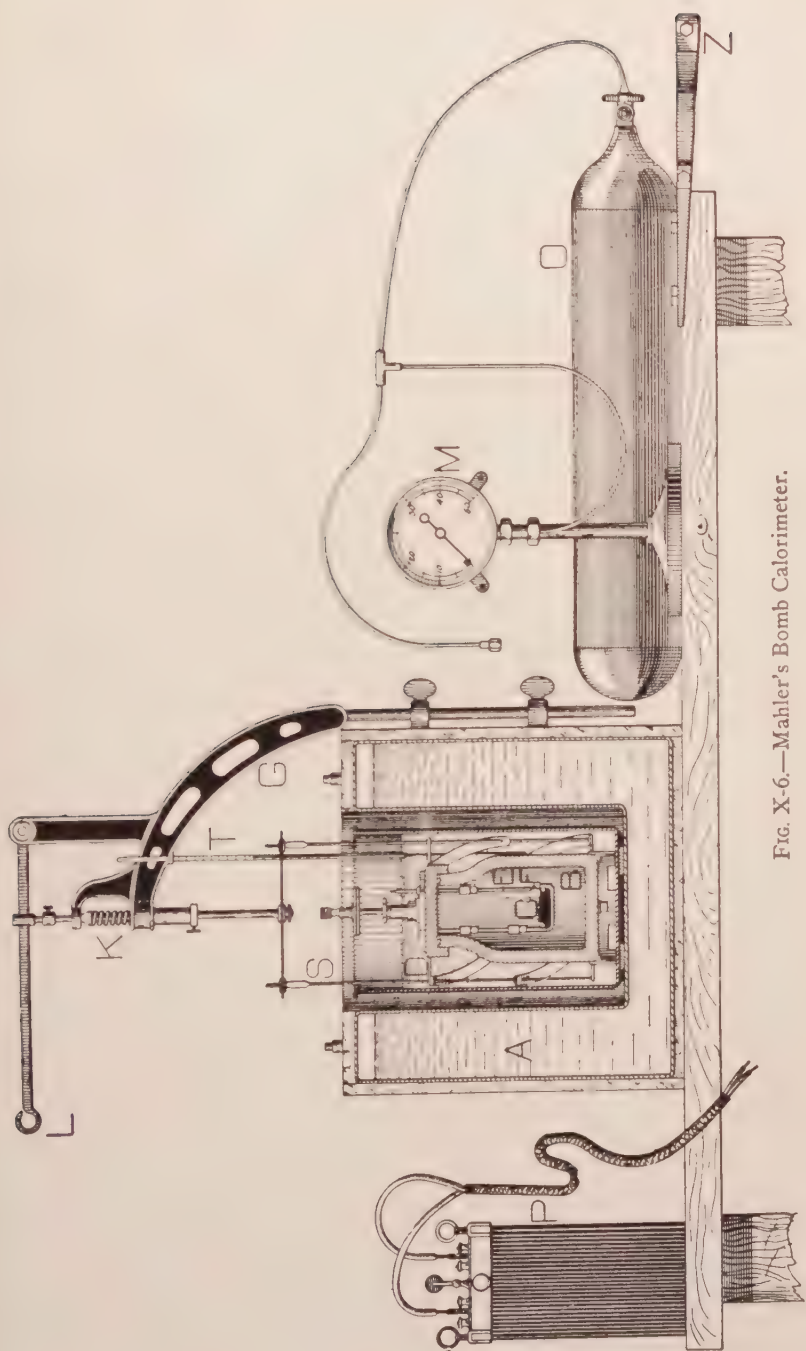


FIG. X-6.—Mahler's Bomb Calorimeter.

The figure shows a flask for oxygen, containing about 1,000 liters. It is ordinarily supplied in this manner at about 120 atmospheres pressure. Since the pressure convenient for the combustion of one gram of coal is only about 25 atmospheres, there is thus a provision for about 60 tests.

A high-grade thermometer, reading to $\frac{1}{50}^{\circ}$ C., an electric battery of 12 volts and 2 amperes capacity, and a stop watch, complete the apparatus.

The following method of procedure for determining the calorific value of a solid or liquid combustible is that given by the inventor of the apparatus: One gram of the fuel is weighed and placed in tray *C*. The small iron wire *F*, of known weight, is adjusted in contact with the fuel and serves as a primer. After putting the fuel and wire in the bomb, it is placed in the clamp *Z* and the cap is screwed on hard by means of a heavy hexagonal wrench. The valve on the cap is then opened, the second valve for fine adjustment (not shown) having first been closed. The valve on the flask is then opened, and then, very slowly, the adjusting valve, until the gage indicates twenty-five atmospheres. After having closed all valves, the tube is disconnected.

The bomb thus prepared is placed in the calorimeter *D*. The thermometer *T* and agitator *S* are placed in position, and a measured quantity of water, sufficient to cover the bomb completely, is poured in. This quantity will be about 2,200 cc., which is the amount used by M. Mahler in his experiments. The water is stirred for some minutes, in order to let the whole system arrive at an even temperature; then observations are commenced.

The temperature is noted from minute to minute for five minutes, in order to fix the rate of variation of the thermometer before ignition. At the end of the fifth minute, contact is made and the fuel is fired by means of the battery connected to the electrode *E* and to a point on the valve. Ignition takes place immediately.

The temperature is noted half a minute after contact is made, and then at the end of a minute; and the observations are continued from minute to minute up to the point where the temperature begins to fall regularly. This, then, is the maximum temperature. The observations are then continued for five more minutes, in order to fix the variation of the thermometer after it reaches the maximum. The principal data for the calculations are then at hand, including data for the correction for loss of heat by radiation from the calorimeter. This correction is made according to the following rules, true between large limits, even where the amount of contained water is not more than half the water equivalent of the calorimeter:

(1) The rate of decrease of temperature, observed after reaching the maximum, represents the loss of heat from the calorimeter before reaching

the maximum, provided the fall in temperature is not greater than 1°C . per minute.

(2) If the fall in temperature per minute is greater than 1° , but less than 2°C ., the figure representing the rate of decrease, when diminished by 0.05, gives the desired correction.

The two preceding paragraphs cover all cases. It is possible also, and that without altering the accuracy of the experiment, to consider the variation during the first half of the minute following the ignition as that which exists at the minimum temperature.

During the whole of the experiment the observer should continually operate the agitator. When the observations are ended, the valve on the bomb is first opened, then the bomb itself. The bomb will contain the ordinary products of combustion, composed principally of carbonic acid gas and water, a considerable quantity of free oxygen, and an appreciable quantity of nitric acid formed during the combustion from such nitrogen as was present in the bomb at atmospheric pressure before it was charged with oxygen.

The interior of the bomb is washed with a small quantity of water to remove the liquid acid formed during the combustion. The amount of nitric acid is then determined by a simple chemical analysis, and the calorific value h is determined from the formula:

$$h = r(1 + a)(P + P') - (230p + 1600p'),$$

where r = the rise in temperature.

a = the loss of temperature during the experiment.

P = the weight of water in the calorimeter.

P' = the water equivalent of the calorimeter.

p = the weight of nitric acid.

p' = the weight of the iron ignition wire.

230 = the heat of formation of 1 gram of nitric acid.

1600 = the heat of combustion of 1 gram of iron.

In making a test of coal, no separate account is taken of the quantity of sulphuric acid resulting from the oxidation of the small quantity of sulphur present in the sample, such acid being treated as nitric acid. The error is negligible in ordinary work. It may be noted that the sulphur being entirely oxidized and transformed into sulphuric acid, the bomb gives a means of evaluating it. For this purpose, in order to give a sufficient quantity for satisfactory operation, it will be better to burn 2 grams under 30 atmospheres, without taking readings of the thermometer. If desired, account may be taken of the heat generated by the formation of sulphuric acid, which is 0.73 calorie per gram of acid.

In testing a substance containing but little hydrogen, coke for example, so little water of combustion is formed that the quantity is insufficient to dissolve the acid. It is then best to place in the bottom of the bomb a few cubic centimeters of water, which must be taken into account in making the calculations.

The procedure is the same for a liquid as for a solid. If the liquid gives off vapors, it is well to weigh the sample in a closed vial having thin points through which is passed the ^{filament} of iron wire. At the moment of introducing the vial into the bomb, care should be taken to break these points in order to bring the oxygen into contact with the liquid.

This apparatus has also been used for the determination of the calorific value of various gases. After having exhausted the bomb and measured the pressure remaining, the gas is introduced for the first time. The bomb is then exhausted the second time, after which it is filled with the gas at atmospheric pressure, and at the temperature of the laboratory. The oxygen is then added and the procedure is carried on in the same manner as for solid and liquid fuels.

The determination of the calorific value of gases offers a special difficulty. If diluted with too great a quantity of oxygen, the mixture will not be combustible. Five atmospheres are sufficient for illuminating gas and one-half an atmosphere for producer gas, measured on a mercurial manometer.

Determination of the water equivalent of the system.—In order to determine the value of P' , the term representing in water the exact equivalent of the system, the simplest method is to perform a double experiment as follows:

Burn in the bomb a known weight, 1 gram for example, of a combustible of fixed composition, such as fuel oil, and with 2,300 grams of water in the calorimeter. Then burn the same weight of the same combustible with only 2,100 grams of water in the calorimeter. There will then be two equations between which the heat of combustion of the fuel may be eliminated and the value of the water equivalent may be reduced.

Example.—The following example of the work of the apparatus is given by M. Mahler. The fuel under test is a sample of colza oil; an approximate analysis gave: carbon, 77.182; hydrogen, 11.711; oxygen and nitrogen, 11.107; weight of sample tested, 1 gram; water in calorimeter, 2,200 grams; water equivalent of the bomb and accessories, previously determined, 481 grams.

The apparatus being prepared, as above directed, a little time is allowed to elapse for the temperature to equalize; then the stop watch is started and the temperatures are noted as below.

PRELIMINARY PERIOD

0 minutes	10.23°
1 minute	10.23
2 minutes	10.24
3 minutes	10.24
4 minutes	10.25
5 minutes	10.25

$$r_v = \frac{10.25^\circ - 10.23^\circ}{5} = 0.004^\circ$$

The combustible is then fired.

PERIOD OF COMBUSTION

5½ minutes	10.80°
6 minutes	12.90
7 minutes	13.79
8 minutes	13.84 (max.)

FINAL PERIOD

9 minutes	13.82°
10 minutes	13.81
11 minutes	13.80
12 minutes	13.79
13 minutes	13.78

$$r_v = \frac{13.84^\circ - 13.78^\circ}{5} = 0.012^\circ$$

No further readings of the thermometer are taken.

The change in temperature has been $13.84^\circ - 10.25^\circ = 3.59^\circ$.

Corrections.—The apparatus has lost, during the minutes (7, 8), (6, 7),

quantity of heat measured by $\frac{13.84^\circ - 13.78^\circ}{5} \times 2 = .024^\circ$.

During the half minute (5½, 6), it has lost a quantity of heat represented by $(0.012 - 0.005) \times \frac{1}{2} = 0.0035^\circ$; and during the half minute (5,

½) it gained $\frac{10.25^\circ - 10.23^\circ}{5} \times \frac{1}{2} = .004^\circ \times \frac{1}{2} = .002^\circ$.

Finally, the loss during the minute (5, 6) is $0.0035 - 0.002 = .0015^\circ$.

To sum up, the loss during the whole experiment has been $0.024 + .0015^\circ = 0.0255^\circ$, a quantity which should be added to the 3.59° already found. The corrected rise in temperature is then 3.615° , neglecting the ten-thousandths.

The quantity of heat observed is, therefore, $(2,200 + 481) \times 3.615 = 6,691.8$ calories.

In order to obtain the final result, we subtract from this figure:

1. The heat of formation of 0.13 gram of nitric acid, determined volumetrically, $0.13 \times 230 = 29.9$ calories.
2. The heat of combustion of 0.025 gram of iron wire, $0.025 \times 1,600 = 40$ calories.



FIG. X-7.—Liquid-Fuel Portable Test Outfit.

Amount to be deducted, 69.9 calories.

The final result is then $9,691.8 - 69.9 = 9,621.9$ calories, or, for a kilogram of oil, 9,621.9 kilo-calories.

To transform this result into B.t.u.'s per pound, multiply by 1.8: $9,621.9 \times 1.8 = 17,319.42$ B.t.u.'s.

Applying the formula $h = 14,500 [C + 4.28 (H - \frac{O}{8})]$, we obtain for h the theoretical value 17,597.

Liquid-fuel portable test outfit. A liquid-fuel portable test outfit that is furnished to all vessels that burn oil, and to all oil supply stations, is shown in Fig. X-7. The apparatus at the right is the Pensky-Martens flash tester, which is shown in detail in Fig. X-8.

This outfit has instruments for determining the flash point, percentage of water and sediment, and specific gravity of liquid fuel. Samples are sent to the chemical laboratories at navy yards at Norfolk and Washington for the determination of the percentage of sulphur and the heating value.

Pensky-Martens flash tester.—The Pensky-Martens apparatus for flash-point determination is shown in Fig. X-8.

E is the oil container, which is placed in a metal heating vessel H , provided with a mantle L , in order to protect H from loss of heat by radiation. The oil cup E is closed by a tightly fitting lid, shown in plan 2. Through the center of the lid passes a shaft carrying the stirring arrangement, which is worked through a flexible connection by means of the handle J . In another opening of the cover is fixed a thermometer. The lid is perforated with several orifices, which are left open or covered, as the case may be, by a sliding cover. This can be rotated by turning the vertical spindle with milled head G . By turning G , an opening of the slide can be made to coincide with an orifice in the cover, and simultaneously a jet of flame P , from a very small spirit lamp, is tilted on the surface of the oil. This contrivance is shown better in plan 2.

Operation.—All water which is contained in the oil must be removed

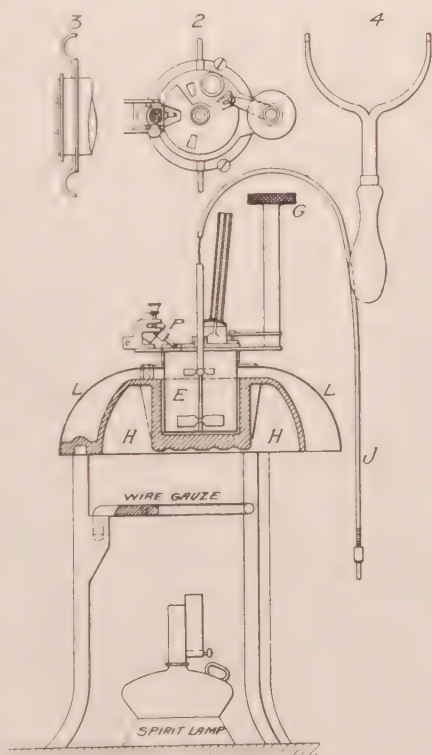


FIG. X-8—The Pensky-Martens Flash Tester.

before testing for flash point, by filtering it through one of the small felt filters and funnels contained in the outfit. When the sample is prepared for test, the oil cup is filled up to the mark, the cover is fixed, and the oil is heated rapidly until its temperature reaches a point about 50° F. below the expected flash point. The wire-gauze screen shown in the figure is then placed in position, and the rate of rise in temperature is thus reduced to about 5° F. per minute. Handle *J* is turned slowly and continuously for stirring. From time to time the milled head *G* is turned, opening the shutter at the top of the cup and tilting the flame *P* into it. This is done at 5° F. rise in temperature until near the probable flash point when the intervals are made 2° F. When the flash point is reached, there will be a light explosion when the flame is tilted down.

A sample can be used for only one test, since the more volatile products are given off and a subsequent test would show a higher flash point.

The fire test.—This is the temperature at which the oil will give off vapors which, when ignited, will burn continuously. It is made by continuing to heat the oil after the flash point has been determined. In this apparatus the cover is removed after the flash point has been determined; the thermometer is left in place. When the fire test is completed, the flame is extinguished by replacing the cover.

Test for determining water and sediment.—The outfit contains a graduated glass cylinder, as shown in Fig. X-7, having a small stem at the bottom, of 3 cc. capacity. Fifty cubic centimeters of the oil under test is placed in the cylinder, and an equal quantity of gasoline or kerosene is added. The whole is then shaken thoroughly and allowed to stand for at least two hours. All of the water and sediment will then be found to have settled in the narrow stem, where it can be measured. If bubbles are found to be adhering to the glass, they are removed with a thin wire agitator. Each cubic centimeter of water and sediment found in the stem will represent 2 per cent in the sample tested.

Specific gravity.—A sample of the oil is placed in the graduated glass jar, Fig. X-7, and a hydrometer is slowly sunk into it. Care must be taken not to plunge the hydrometer deeper than it will float, as this will make an accurate reading impossible. After reading the hydrometer, it is removed and the temperature is taken. By means of a correction table, the specific gravity is reduced to 60° F., which is the standard for comparison.

Commercially, the specific gravity of an oil in the United States is usually given according to the Baumé or A.P.I. scales, arbitrary standards, whose value at various points is as follows, the weight per gallon being given as 60° F.:

10	Baumé	=	specific gravity 1.000	= 8.331 pounds per gallon.
15	"	=	"	.967 = 8.056 "
20	"	=	"	.936 = 7.798 "
25	"	=	"	.907 = 7.556 "
30	"	=	"	.880 = 7.331 "
35	"	=	"	.854 = 7.115 "
40	"	=	"	.830 = 6.915 "
45	"	=	"	.807 = 6.723 "
50	"	=	"	.785 = 6.540 "
55	"	=	"	.765 = 6.373 "
60	"	=	"	.745 = 6.206 "

4. HEAT BALANCE

Calculations from the results of analyses.—One of the principal results derived from gas and coal analyses is the *heat balance*, which shows:

- (A) The calorific value of the fuel.
 - (B) The heat absorbed by the boiler.
 - (C) The loss due to the sensible heat in the smoke pipe or waste gases.
 - (D) The loss due to latent heat in steam gases in smoke-pipe gases.
 - (E) Loss due to incomplete combustion.
 - (F) Other losses due to radiation and otherwise unaccounted for.
- (A) **Calorific value of the fuel.**—Suppose the chemical analysis of a coal as fired gave, in per cent, 83.5 C, 4.8 H, 3.2 O, 1.2 N, 0.5 S, 1.5 moisture, and 5.3 ash.

To reduce this to combustible* as a base, it must be remembered that the combustible portion of a coal as fired is 100% — (per cent of moisture + per cent of ash). The per cent of combustible in this coal will then be $100 - (1.5 + 5.3) = 93.2\%$. The percentages of C, H, O, N, and S in the combustible will then be

$$83.5 \times \frac{100}{93.2} = 89.6 \text{ C}; 4.8 \times \frac{100}{93.2} = 5.15 \text{ H}; 3.2 \times \frac{100}{93.2} = 3.35 \text{ O};$$

$$1.2 \times \frac{100}{93.2} = 1.29 \text{ N}; \text{ and } 0.5 \times \frac{100}{93.2} = 0.545 \text{ S}.$$

From Dulong's formula, which is heat units = $\frac{1}{100} [14,000 \text{ C} + 62,000 (\text{H} - \frac{\text{O}}{8})]$, we get 16,015 as the calorific value per pound of combustible.

*This is reduced to combustible as a base because the heat units are obtained from only the combustible constituents of the coal.

(B) **Heat absorbed by the boiler.**—This must be found from an evaporative test of a boiler; and let us suppose that in this case the number of pounds of water evaporated from and at 212° F. was 11.6 per pound of combustible. The heat absorbed by the boiler water was then 11.6×970.4 (970.4 is the latent heat of steam at 212° F.). = 11,257 B.t.u.

(C) **Loss due to sensible heat in waste gases** (per pound of combustible).—This is obtained from the analysis of the smoke-pipe gases and the ultimate analysis of the fuel (per pound of combustible).

There are two parts of this computation: (1) The calculation of the number of pounds of dry gas per pound of combustible, and (2) the calculation of the number of pounds of steam gas per pound of combustible from the per cent of H in the ultimate fuel analysis and from the per cent of moisture per pound of combustible.

Calculation (1).—Let us assume that the analysis of the smoke-pipe gases gave, in per cent, 12.7 CO_2 , 5.7 O, 0.5 CO, and 81.1 N (by difference). The per cent of N is found by taking $100 - (\text{CO}_2 + \text{CO} + \text{O})$. The calculations of the heat lost in the smoke-pipe gas are based on the supposition that the dry gas contains only CO_2 , CO, O, and N. The gas may contain very slight amounts of H (decomposed from the moisture in the coal, probably just after firing), CH_4 , (distilled from the coal and not burned) and SO_2 and NO_2 (from the sulphur and nitrogen in the coal). These last four gases are included in the per cent of N, as they are so small in amount that they may be neglected.

From chemistry it is learned that the weight of a gas is equal to its molecular weight, referred to hydrogen as unity. Each molecule of the gases H, O, and N contains two atoms; their molecular weights are, therefore, twice their atomic weights.

Atomic weights: O = 16, H = 1, C = 12, and N = 14. The molecular weights of hydrogen and of the gases found from burning carbon in air are: H = 2, O = 16, N = 28, CO_2 = 12 + 32 = 44, CO = 12 + 16 = 28.

In CO_2 carbon forms (by weight $\frac{12}{44}$, and oxygen $\frac{32}{44}$, or $\frac{3}{11}$ and $\frac{8}{11}$, respectively. In CO carbon forms $\frac{12}{28}$, and oxygen $\frac{16}{28}$, or $\frac{3}{7}$ and $\frac{4}{7}$, respectively.

The weight of the dry gases will then be the percentage (found by the analysis) of each gas multiplied by its molecular weight.

Pounds of dry gas = $\% \text{CO}_2 \times 44 + \% \text{O} \times 32 + \% \text{CO} \times 28 + \% \text{N} \times 28$. The pounds of dry gas per pound of carbon burned will be this number of pounds divided by the number of pounds of carbon in the gases containing carbon. The gases containing carbon are CO_2 and CO. The number of pounds of gases containing carbon will then be $\% \text{CO}_2 \times 44 + \% \text{CO} \times 28$, and the weight of carbon in these gases will then be

$\frac{3}{11} \times \% \text{CO}_2 \times 44 + \frac{3}{7} \times \% \text{CO} \times 28 = 12 (\text{CO}_2 + \text{CO})$,
 is $\frac{3}{11}$ of CO_2 and $\frac{3}{7}$ of CO is carbon by weight. Letting the symbols represent the percentages by volume:

Pounds of dry gas per pound of carbon burned

$$\frac{44 \text{ CO}_2 + 32 \text{ O} + 28 \text{ CO} + 28 \text{ N}}{12 (\text{CO}_2 + \text{CO})} - \frac{11 \text{ CO}_2 + 8 \text{ O} + 7 \text{ CO} + 7 \text{ N}}{3 (\text{CO}_2 + \text{CO})}$$

Dry gas per pound of carbon

$$= \frac{3 (12.7 + 0.5)}{11 \times 12.7 + 8 \times 5.7 + 7 (0.5 + 81.1)} = 19.1 \text{ lbs.}$$

To reduce this to dry gas per pound of combustible, we must multiply it by $\frac{89.6}{100}$, or

$$\text{Dry gas per pound of combustible} = 19.1 \times \frac{89.6}{100} = 17.1 \text{ lbs.}$$

Calculation (2) - In forming water, one part by weight of hydrogen combines with eight parts by weight of oxygen to form nine parts by weight of water. Therefore the weight of H per pound of combustible multiplied by 9 gives the weight of water formed per pound of combustible when it is burned. The steam gas per pound of combustible from the hydrogen would therefore be $.0515 \times 9 = .464 \text{ lb.}$ In addition there was 1.5% of moisture

in the coal, and this forms $\frac{.015 \times 100}{93.2} = .016 \text{ lb.}$ of steam gas per pound of combustible.

Summing up from calculations (1) and (2):

Dry gas per pound of combustible..... = 17.1 lbs.
 Steam gas from H in fuel per pound of combustible..... = .464 lb.
 Steam gas from moisture in fuel per pound of combustible... = .016 lb.

Total gas* per pound of combustible..... 17.580 lbs.

* This can be reduced to pounds of gas per pound of coal or per pound of carbon, if desired.

Suppose the temperature of the gases in the uptake to be 590°F. and that of the external air 75°F. For all practical purposes, and in view of the approximate results which can be obtained by the present means of gas analysis, the average specific heat of the dry gases may be taken as 0.24, and of the dry gases and steam gases combined, as 0.246.

The rise in temperature of the gases is $590 - 75 = 515^\circ \text{F.}$, and the product of the number of pounds of gases by the rise in temperature, in

degrees F., by the specific heat of the gases equals the number of B.t.u.'s. lost. 17.58 (lbs. of gases per lb. of combustible) $\times 515$ (rise in temperature) $\times .246$ (specific heat of gases) = $2,227.4$ B.t.u.'s. lost, the loss due to the sensible heat in the waste gases per pound of combustible.

(D) **Loss due to latent heat in steam gases.**—The loss due to the sensible heat has been accounted for in calculation (C). In addition, there is the loss of heat rendered latent in changing the water formed from the H. and the moisture in the coal from water into steam. The latent heat of one pound of steam under atmospheric pressure of 14.7 pounds per square inch is 970.4 B.t.u.'s. As there was 0.48 pound of water formed per pound of combustible in the above example, this loss in B.t.u.'s. is $970.4 \times .48 = 465.8$.

(E) **Loss due to incomplete combustion.**—As found before, the weight of the carbon in the gases containing carbon was 12 ($\text{CO}_2 + \text{CO}$). The perfect, or complete, combustion of this total carbon would have given $12 (\text{CO}_2 + \text{CO}) \times 14,600$ B.t.u.'s. = (a). But the combustion of the carbon, as shown by the gas analysis, was not complete, and the heat generated was, therefore, only $12 \text{ CO}_2 \times 14,600 + 12 \text{ CO} \times 4,451$ B.t.u.'s. = (b). The difference between (a) and (b) will give the loss in B.t.u.'s. due to incomplete combustion of carbon, or loss (a) — (b) = $12 \text{ CO} \times 10,149$ B.t.u.'s. per pound of carbon, or, in per cent of (a)

$$= \frac{12 \text{ CO} \times 10,149 \times 100}{12 (\text{CO}_2 + \text{CO})} = \frac{\text{CO} \times 10,149 \times 100}{\text{CO}_2 + \text{CO}}$$

per lb. of carbon. Per pound of combustible this loss

$$= \frac{\text{CO} \times 10,149}{\text{CO}_2 + \text{CO}} \times \frac{\% \text{C in combustible}}{100}$$

Substituting values from the above gas analysis, we get loss due to incomplete combustion, per pound of combustible,

$$= \frac{.5 \times 10,149}{12.7 + .5} \times \frac{89.6}{100} = 344.4 \text{ B.t.u.'s.}$$

(F) **Loss due to radiation and otherwise unaccounted for.**—This is taken as the difference between (A), the calorific value of one pound of the combustible in B.t.u.'s., and the sum of the values in (B), (C), (D), and (E) in B.t.u.'s.

Heat balance.—From the above calculations the heat balance is made up, which shows the approximate distribution of the heating value of one pound of the combustible.

HEAT BALANCE FROM THE ANALYSES GIVEN

Calorific value of the combustible	16,015 B.t.u's.
Absorbed by the boiler water	11,257
Loss due to sensible heat in waste gases	2,227.4
Loss due to latent heat in steam gases	465.8
Loss due to incomplete combustion	344.4
Loss due to radiation and otherwise unaccounted for	1,720.0
	16,015.0

These values are frequently expressed in per cent of the calorific value of the combustible.

APPENDIX

TABLE I.
PROPERTIES OF SATURATED STEAM.
BRITISH UNITS.

Pressure in pounds per square inch, ab- solute.	Tempera- ture of boiling point, degrees Fahr.	Sensible heat of the liquid, above 32° Fahr.	Total heat of steam, above 32° Fahr.	Latent heat of evapora- tion.	Specific volume, cubic feet per pound.	Density, pounds per cubic foot.
<i>p.</i>	<i>t.</i>	<i>h.</i>	<i>H.</i>	<i>L.</i>	<i>v.</i>	<i>1/v.</i>
1	101.83	69.8	1104.4	1081.6	333.0	0.00300
5	162.28	130.1	1130.5	1000.3	73.33	0.01364
10	193.22	161.1	1143.1	982.0	38.38	0.02606
14.7	212.0	180.0	1150.4	970.4	26.79	0.03732
15	213.0	181.0	1150.7	969.7	26.27	0.03806
20	228.0	196.1	1156.2	960.0	21.08	0.04980
25	240.1	208.4	1160.4	952.0	16.30	0.0614
30	250.3	218.8	1163.9	945.1	13.74	0.0728
35	259.3	227.9	1166.8	938.9	11.89	0.0841
40	267.3	236.1	1169.4	933.3	10.49	0.0953
45	274.5	243.4	1171.6	928.2	9.39	0.1065
50	281.0	250.1	1173.6	923.5	8.51	0.1175
55	287.1	256.3	1175.4	919.0	7.78	0.1285
60	292.7	262.1	1177.0	914.9	7.17	0.1394
65	298.0	267.5	1178.5	911.0	6.65	0.1503
70	302.9	272.6	1179.8	907.2	6.20	0.1612
75	307.6	277.4	1181.1	903.7	5.81	0.1721
80	312.0	282.0	1182.3	900.3	5.47	0.1829
85	316.3	286.3	1183.4	897.1	5.16	0.1937
90	320.3	290.5	1184.4	893.9	4.89	0.2044
95	324.1	294.5	1185.4	890.9	4.65	0.2151
100	327.8	298.3	1186.3	880.0	4.429	0.2258
105	331.4	302.0	1187.2	885.2	4.230	0.2365
110	334.8	305.5	1188.0	882.5	4.047	0.2472
115	338.1	309.0	1188.8	879.8	3.880	0.2577
120	341.3	312.3	1189.6	877.2	3.726	0.2683
125	344.4	315.5	1190.3	874.7	3.583	0.2791
130	347.4	318.6	1191.0	872.3	3.452	0.2897
135	350.3	321.7	1191.6	869.9	3.331	0.3002
140	353.1	324.6	1192.2	867.6	3.219	0.3107
145	355.8	327.4	1192.8	865.4	3.112	0.3213
150	358.5	330.2	1193.4	863.2	3.012	0.3320
155	361.0	332.9	1194.0	861.0	2.920	0.3425
160	363.6	335.6	1194.5	858.8	2.834	0.3529
165	366.0	338.2	1195.0	856.8	2.753	0.3633
170	368.5	340.7	1195.4	854.7	2.675	0.3738
175	370.8	343.2	1195.9	852.7	2.602	0.3843
180	373.1	345.6	1196.4	850.8	2.533	0.3948
185	375.4	348.0	1196.8	848.4	2.468	0.4052
190	377.6	350.4	1197.3	846.9	2.406	0.4157
195	379.8	352.7	1197.7	845.0	2.346	0.4262
200	381.9	354.9	1198.1	843.2	2.290	0.437
205	384	357.1	1198.5	841.4	2.237	0.447
210	386	359.2	1198.8	839.6	2.187	0.457
215	388	361.4	1199.2	837.9	2.138	0.468
220	389.9	363.4	1199.6	836.2	2.091	0.478
225	391.9	365.5	1199.9	834.4	2.046	0.489
230	393.8	367.5	1200.2	832.1	2.004	0.499
235	395.6	369.4	1200.6	831.1	1.964	0.509
240	397.4	371.4	1200.9	829.5	1.924	0.520
245	399.3	373.3	1201.2	827.9	1.887	0.530
250	401.1	375.2	1201.5	826.3	1.850	0.541
260	404.1	378.9	1202.1	823.1	1.782	0.561
270	407.9	382.5	1202.6	820.1	1.718	0.582
280	411.2	386.0	1203.1	817.1	1.658	0.603
290	414.4	389.4	1203.6	814.2	1.602	0.624
300	417.5	392.7	1204.1	811.3	1.551	0.645
310	420.5	395.9	1204.5	808.5	1.502	0.666
320	423.4	399.1	1204.9	805.8	1.456	0.687
330	426.3	402.2	1205.3	803.1	1.413	0.708
340	429.1	405.3	1205.7	800.4	1.372	0.729
350	431.9	408.2	1206.1	797.8	1.334	0.750

TABLE I.—Continued.

Pressure in pounds per square inch, absolute.	Temperature of boiling point, degrees Fahr.	Sensible heat of the liquid, above 32° Fahr.	Total heat of steam, above 32° Fahr.	Latent heat of evaporation.	Specific volume, cubic feet per pound.	Density, pounds per cubic foot.
P.	t.	h.	H.	L.	v.	1/v.
360	431.6	411.2	1206.4	795.3	1.298	0.770
370	437.2	414.0	1206.8	792.8	1.264	0.791
380	439.8	416.8	1207.1	790.3	1.231	0.812
390	442.3	419.5	1207.4	787.9	1.200	0.833
400	444.8	422.0	1208.0	786.0	1.17	0.86
450	456.5	435.0	1209.0	774.0	1.04	0.96
500	467.3	448	1210.0	762.0	0.93	1.08
550	477.3	459	1210.0	751.0	0.83	1.20
600	486.6	460	1210.0	741.0	0.76	1.32

The pressures in this table are absolute pressures. Convert the corrected barometer reading into pounds per square inch, add this pressure to the gage pressure, and with this absolute pressure enter the table for the desired data.

Tables I and II are adapted from Marks & Davis' Steam Tables, by the kind permission of Professor Lionel S. Marks and Longmans Green & Co., publishers. Marks & Davis' Tables are now considered standard by the Bureau of Engineering.

TABLE II.

Absolute pressures in inches of mercury.	Absolute pressures in pounds per square inch.	Temperature of boiling-point, degrees Fahr.	Sensible heat of the liquid above 32° Fahr.	Total heat above 32° Fahr.	Latent heat of evaporation.	Specific volume, cubic feet per pound.	Density, pounds per cubic foot.
p.	t.	h.	H.	L.	v.	1/v.	
.1804	0.0886	32	0.00	1073.4	1073.4	3274	.000304
.5	0.2463	58.9	26.98	1085.36	1058.36	1253.2	.000798
1.0	0.4909	79.1	47.14	1094.35	1047.24	654.98	.001528
1.5	0.7364	91.8	59.80	1100.00	1040.12	444.86	.002248
2.0	0.984	101.3	69.27	1104.15	1004.92	338.15	.002558
2.5	1.228	108.8	76.74	1107.42	1039.72	273.49	.003644
3.0	1.475	115.2	83.12	1110.23	1027.1	230.68	.004335
3.5	1.717	120.6	88.51	1112.60	1021.1	200.22	.005002
4.0	1.965	125.5	93.40	1114.75	1021.35	176.15	.005678
4.5	2.207	129.8	97.69	1116.60	1018.92	157.90	.006337
5.0	2.461	133.9	101.78	1118.36	1016.56	142.56	.00701
5.5	2.705	137.5	105.37	1119.90	1014.55	130.50	.00767
6.0	2.945	140.8	108.67	1121.32	1012.70	120.64	.00830
6.5	3.187	143.9	111.77	1122.66	1010.86	111.97	.00894
7.0	3.438	146.9	114.76	1123.96	1009.16	104.25	.00960
7.5	3.678	149.6	117.46	1125.10	1007.64	97.82	.01022
8.0	3.931	152.3	120.16	1126.22	1006.05	91.97	.01088
8.5	4.179	154.8	122.66	1127.32	1004.62	86.80	.01152
9.0	4.419	157.1	124.96	1128.24	1003.34	82.41	.01214
9.5	4.670	159.4	127.26	1129.34	1001.96	78.22	.01279
10.0	4.909	161.5	129.36	1130.25	1000.80	74.65	.01340
10.5	5.159	163.6	131.46	1131.04	999.54	71.24	.01405
11.0	5.397	165.5	133.36	1131.40	998.45	68.35	.01464
11.5	5.655	167.5	135.36	1132.60	997.30	65.40	.01530
12.0	5.896	169.3	137.16	1133.42	996.22	62.91	.01590
12.5	6.145	171.1	138.97	1134.14	995.14	60.57	.01653
13.0	6.385	172.8	140.67	1134.82	994.12	58.36	.01714
14	6.883	176.1	143.87	1136.24	992.26	54.39	.01838
15	7.377	179.2	147.08	1137.50	990.38	52.09	.01961
16	7.867	182.1	149.99	1138.64	988.64	48.04	.02082
17	8.344	184.8	152.69	1139.72	987.02	45.43	.02201
18	8.836	187.4	155.30	1140.76	985.46	43.11	.02320
19	9.32	189.9	157.81	1141.76	983.96	41.19	.02442
20	9.82	192.4	160.31	1142.76	982.46	38.00	.02564
22	10.81	196.9	164.83	1144.56	979.76	35.69	.02793
24	11.79	201.1	169.04	1146.24	977.14	32.90	.03040
26	12.77	205.0	172.96	1147.4	974.7	30.53	.03276
28	13.77	208.7	176.06	1149.1	972.3	28.43	.03518
29.92	14.70	212.0	180.0	1150.4	970.4	26.79	.03732

With pressures less than atmospheric, subtract the vacuum in inches of mercury from the corrected barometer reading and with the remaining pressure in inches of mercury enter the table for the desired results.

TABLE I B.

OXYGEN AND AIR REQUIRED FOR THE COMBUSTION OF CARBON, HYDROGEN, ETC.

Element or substance burned.	Burned to—	Chemical reaction.	Combining weights.	Calculation.	Lbs. of O per lb. of substance.	Lbs. NO $\times$ 8.32.	Air per lb. $\times$ 4.32	Gases produced per lb.
C	CO ₂	C+2O	12+32	32+12	2 $\frac{2}{3}$	8.85	11.52	12.52
C	CO	C+O	12+16	16+12	1 $\frac{1}{3}$	4.43	5.76	6.76
CO	CO ₂	CO+O	28+16	16+28	$\frac{8}{7}$	1.90	2.47	3.47
H	H ₂ O	2H+O	2+16	16+2	8	25.76	34.56	35.56
C	CO ₂ & 2H ₂ O	C+1H+4O	16+64	64+16	4	13.28	17.28	18.28
S	SO ₂	S+2O	32+32	32+32	1	3.32	4.32	5.32

DENSITIES OF GASES.*

Element or substance.	Symbol.	Specific gravity, air, 1.	Weight of 1 cubic foot.	Relative density, H, 1.	Relative density, approximate.
Oxygen.....	O	1.10521	.088843	15.96	16
Nitrogen.....	N	.9701	.078314	14.01	14
Hydrogen.....	H	.069234	.005589	1.	1
Carbon dioxide.....	CO ₂	1.51968	.122681	21.95	22
Carbon monoxide.....	CO	.96709	.078071	13.97	14
Marsh gas (methane).....	CH ₄	.55217	.04464	7.99	8
Ethylene.....	C ₂ H ₄	.96744	.07810	13.97	14
Acetylene.....	C ₂ H ₂	.8982	.07801	12.97	13
Sulphur dioxide.....	SO ₂	2.21235	.178616	31.96	32
Air.....		1.	.080728		

* The first column of figures is based on Hempel's Gas Analysis, and the second on the weight of air by Rankine, .080728 at 32° F. and at atmospheric pressure.

TABLE I C. Properties of superheated steam

[v = Specific volume in cubic feet per pound. i = Total heat in B. t. u. per pound. s = Entropy]

Pressure, pound per square inch, absolute	Temperature of saturated steam, degrees F.	Superheat, degrees F.																															
		20	40	60	80	100	150	200	250	300																							
20	228.0	29.73 1,165.7 1,745.6 10.83 1,179.3 1,689.5 7.40 1,187.3 1,668 3.65 1,193.0 1,633.8 4.58 1,197.5 1,616.0 3.85 1,201.1 1,601.6 3.32 1,204.3 1,589.4 2.93 1,207.0 1,578.9 2.62 1,209.4 1,569.7 2.37 1,211.6 1,561.4 2.16 1,213.6 1,554.1 1.99 1,215.4 1,547.6 1.84 1,217.1 1,541.6 1.72 1,218.7 1,536.2 1.60 1,220.2 1,531.0	21.37 1,175.2 1,737 11.16 1,189.1 1,702.5 7.63 1,197.5 1,698 3.83 1,203.6 1,649 4.72 1,208.4 1,629.4 3.98 1,212.4 1,615.2 3.44 1,215.8 1,603.1 3.03 1,218.8 1,592.8 2.71 1,221.5 1,583.8 2.45 1,223.9 1,575.7 2.24 1,226.2 1,568.6 2.06 1,228.3 1,562.3 1.91 1,230.3 1,556.4 1.78 1,232.2 1,551.2 1.66 1,234.1 1,546.2	22.01 1,184.6 1,771.6 11.50 1,198.9 1,715.1 7.86 1,207.7 1,682.3 4.06 1,214.0 1,659.4 4.86 1,219.1 1,642.0 4.10 1,223.3 1,627.9 3.54 1,226.8 1,615.9 3.12 1,230.0 1,605.6 2.80 1,233.8 1,597.7 2.53 1,236.5 1,589.6 2.31 1,237.9 1,581.6 2.13 1,240.1 1,575.3 1.97 1,242.3 1,569.5 1.84 1,244.3 1,564.3 1.72 1,246.2 1,559.4	22.63 1,194.1 1,780 11.82 1,208.7 1,727.3 8.08 1,217.7 1,694.4 4.18 1,224.2 1,671.6 5.00 1,229.5 1,654.1 4.22 1,233.5 1,640.0 3.65 1,237.5 1,628.0 3.23 1,240.8 1,617.7 2.88 1,243.8 1,608.8 2.61 1,246.5 1,600.7 2.38 1,248.9 1,596.6 2.20 1,251.3 1,589.5 2.04 1,253.4 1,581.5 1.90 1,255.5 1,576.2 1.78 1,257.1 1,571.3	23.25 1,203.5 1,796.1 12.13 1,218.4 1,739.2 8.30 1,227.6 1,706.2 4.34 1,234.3 1,683.3 5.14 1,239.7 1,665.8 4.33 1,244.1 1,651.7 3.75 1,248.0 1,639.5 3.30 1,251.3 1,629.2 2.96 1,254.3 1,620.1 2.68 1,257.1 1,612.0 2.45 1,259.6 1,604.9 2.28 1,261.9 1,598.5 2.10 1,264.1 1,592.6 1.95 1,266.2 1,587.3 1.83 1,268.2 1,582.4	23.85 1,211.1 1,801 12.93 1,234.4 1,767.4 8.84 1,252.1 1,734.2 4.73 1,259.0 1,711.0 5.47 1,264.7 1,693.3 4.62 1,269.3 1,678.9 4.00 1,273.3 1,666.6 3.53 1,276.8 1,656.1 3.16 1,279.9 1,646.8 2.86 1,282.6 1,638.5 2.62 1,285.2 1,631.2 2.42 1,287.6 1,624.6 2.24 1,289.9 1,618.6 2.09 1,291.9 1,613.3 1.96 1,294.0 1,608.2	24.48 1,217.0 1,808 13.70 1,240.3 1,780 9.89 1,260.4 1,750 4.88 1,267.2 1,728.0 5.17 1,271.4 1,705 4.48 1,275.2 1,691.6 3.74 1,278.8 1,704.3 3.35 1,282.5 1,694.8 3.04 1,285.7 1,686.2 2.78 1,288.2 1,678.7 2.57 1,290.8 1,672.0 2.39 1,292.9 1,665.8 2.22 1,294.9 1,660.3 2.09 1,296.9 1,655.0	25.05 1,223.1 1,819 14.48 1,242.4 1,800 10.41 1,262.4 1,780 5.89 1,269.2 1,758 6.12 1,273.4 1,742.8 5.41 1,277.4 1,728.0 4.71 1,281.2 1,715.2 3.95 1,284.8 1,704.3 3.54 1,288.5 1,694.8 3.21 1,291.7 1,686.2 2.94 1,294.2 1,678.7 2.71 1,296.7 1,672.0 2.52 1,299.0 1,665.8 2.35 1,301.2 1,660.3 2.21 1,303.4 1,655.0	25.63 1,229.0 1,824 15.25 1,244.4 1,800 11.41 1,264.4 1,760.3 6.73 1,271.2 1,738.8 5.80 1,276.9 1,718.8 4.89 1,281.4 1,704.1 4.24 1,285.2 1,691.6 3.74 1,288.8 1,704.3 3.35 1,292.5 1,694.8 3.04 1,295.7 1,686.2 2.94 1,298.2 1,678.7 2.78 1,300.7 1,672.0 2.57 1,303.2 1,665.8 2.39 1,305.7 1,660.3 2.21 1,308.2 1,655.0	26.21 1,235.0 1,834 16.03 1,246.4 1,800 12.02 1,266.4 1,760.3 7.17 1,272.2 1,746.2 6.44 1,277.2 1,728.0 5.41 1,281.7 1,715.2 4.71 1,285.5 1,704.3 4.15 1,289.2 1,694.8 3.72 1,292.9 1,686.2 3.48 1,296.6 1,678.7 3.21 1,299.7 1,672.0 2.94 1,302.8 1,665.8 2.71 1,305.9 1,660.3 2.52 1,308.9 1,655.0	26.80 1,241.0 1,844 16.70 1,248.4 1,800 12.63 1,268.4 1,760.3 7.73 1,278.2 1,750.2 6.80 1,283.2 1,730.8 5.89 1,287.7 1,718.8 4.89 1,292.2 1,704.1 4.24 1,296.0 1,691.6 4.15 1,299.7 1,704.3 3.72 1,303.4 1,694.8 3.48 1,307.1 1,686.2 3.21 1,310.2 1,678.7 2.94 1,313.2 1,672.0 2.71 1,316.2 1,665.8 2.52 1,319.2 1,660.3 2.21 1,322.2 1,655.0	27.39 1,247.0 1,854 17.35 1,250.4 1,800 13.24 1,270.4 1,760.3 8.30 1,280.2 1,746.2 7.44 1,285.2 1,728.0 6.44 1,289.7 1,715.2 5.41 1,294.2 1,704.1 4.71 1,298.0 1,691.6 4.15 1,301.7 1,704.3 3.72 1,305.4 1,694.8 3.48 1,309.1 1,686.2 3.21 1,312.2 1,678.7 2.94 1,315.2 1,672.0 2.71 1,318.2 1,665.8 2.52 1,321.2 1,660.3 2.21 1,324.2 1,655.0	27.98 1,253.0 1,864 18.00 1,256.4 1,800 13.83 1,276.4 1,760.3 8.84 1,286.2 1,746.2 7.80 1,291.2 1,730.8 6.89 1,295.7 1,718.8 5.89 1,300.2 1,704.1 4.24 1,304.0 1,691.6 4.15 1,307.7 1,704.3 3.72 1,311.4 1,694.8 3.48 1,315.1 1,686.2 3.21 1,318.2 1,678.7 2.94 1,321.2 1,672.0 2.71 1,324.2 1,665.8 2.52 1,327.2 1,660.3 2.21 1,330.2 1,655.0	28.57 1,259.0 1,874 18.65 1,262.4 1,800 14.44 1,282.4 1,760.3 9.35 1,292.2 1,746.2 8.44 1,297.2 1,730.8 7.44 1,301.7 1,718.8 6.44 1,306.2 1,704.1 4.71 1,310.0 1,691.6 4.15 1,313.7 1,704.3 3.72 1,317.4 1,694.8 3.48 1,321.1 1,686.2 3.21 1,324.2 1,678.7 2.94 1,327.2 1,672.0 2.71 1,330.2 1,665.8 2.52 1,333.2 1,660.3 2.21 1,336.2 1,655.0	29.16 1,265.0 1,884 19.30 1,268.4 1,800 15.04 1,288.4 1,760.3 9.89 1,298.2 1,746.2 8.90 1,303.2 1,730.8 7.80 1,307.7 1,718.8 6.89 1,312.2 1,704.1 4.24 1,316.0 1,691.6 4.15 1,319.7 1,704.3 3.72 1,323.4 1,694.8 3.48 1,327.1 1,686.2 3.21 1,330.2 1,678.7 2.94 1,333.2 1,672.0 2.71 1,336.2 1,665.8 2.52 1,339.2 1,660.3 2.21 1,342.2 1,655.0	29.75 1,271.0 1,894 19.95 1,274.4 1,800 15.63 1,294.4 1,760.3 10.41 1,304.2 1,746.2 9.44 1,309.2 1,730.8 8.44 1,313.7 1,718.8 7.44 1,318.2 1,704.1 4.71 1,322.0 1,691.6 4.15 1,325.7 1,704.3 3.72 1,329.4 1,694.8 3.48 1,333.1 1,686.2 3.21 1,336.2 1,678.7 2.94 1,339.2 1,672.0 2.71 1,342.2 1,665.8 2.52 1,345.2 1,660.3 2.21 1,348.2 1,655.0	30.34 1,277.0 1,904 20.60 1,280.4 1,800 16.24 1,304.4 1,760.3 10.96 1,314.2 1,746.2 9.90 1,319.2 1,730.8 8.90 1,323.7 1,718.8 7.80 1,328.2 1,704.1 4.24 1,332.0 1,691.6 4.15 1,335.7 1,704.3 3.72 1,339.4 1,694.8 3.48 1,343.1 1,686.2 3.21 1,346.2 1,678.7 2.94 1,349.2 1,672.0 2.71 1,352.2 1,665.8 2.52 1,355.2 1,660.3 2.21 1,358.2 1,655.0	30.93 1,283.0 1,914 21.25 1,286.4 1,800 16.83 1,310.4 1,760.3 11.41 1,320.4 1,746.2 10.41 1,325.4 1,730.8 9.44 1,329.9 1,718.8 8.44 1,334.4 1,704.1 4.71 1,338.0 1,691.6 4.15 1,341.7 1,704.3 3.72 1,345.4 1,694.8 3.48 1,349.1 1,686.2 3.21 1,352.2 1,678.7 2.94 1,355.2 1,672.0 2.71 1,358.2 1,665.8 2.52 1,361.2 1,660.3 2.21 1,364.2 1,655.0	31.52 1,289.0 1,924 21.90 1,292.4 1,800 17.44 1,316.4 1,760.3 11.96 1,326.4 1,746.2 10.96 1,331.4 1,730.8 9.90 1,335.9 1,718.8 8.90 1,340.4 1,704.1 4.24 1,344.0 1,691.6 4.15 1,347.7 1,704.3 3.72 1,351.4 1,694.8 3.48 1,355.1 1,686.2 3.21 1,358.2 1,678.7 2.94 1,361.2 1,672.0 2.71 1,364.2 1,665.8 2.52 1,367.2 1,660.3 2.21 1,370.2 1,655.0	32.11 1,295.0 1,934 22.55 1,298.4 1,800 18.03 1,322.4 1,760.3 12.41 1,332.4 1,746.2 11.41 1,337.4 1,730.8 10.41 1,341.9 1,718.8 9.44 1,346.4 1,704.1 4.71 1,350.0 1,691.6 4.15 1,353.7 1,704.3 3.72 1,357.4 1,694.8 3.48 1,361.1 1,686.2 3.21 1,364.2 1,678.7 2.94 1,367.2 1,672.0 2.71 1,370.2 1,665.8 2.52 1,373.2 1,660.3 2.21 1,376.2 1,655.0	32.70 1,301.0 1,944 23.20 1,304.4 1,800 18.63 1,328.4 1,760.3 12.96 1,342.4 1,746.2 11.96 1,347.4 1,730.8 10.96 1,351.9 1,718.8 9.90 1,356.4 1,704.1 4.24 1,360.0 1,691.6 4.15 1,363.7 1,704.3 3.72 1,367.4 1,694.8 3.48 1,371.1 1,686.2 3.21 1,374.2 1,678.7 2.94 1,377.2 1,672.0 2.71 1,380.2 1,665.8 2.52 1,383.2 1,660.3 2.21 1,386.2 1,655.0	33.29 1,307.0 1,954 23.85 1,308.4 1,800 19.24 1,334.4 1,760.3 13.51 1,348.4 1,746.2 12.41 1,353.4 1,730.8 11.41 1,357.9 1,718.8 10.41 1,362.4 1,704.1 4.71 1,366.0 1,691.6 4.15 1,369.7 1,704.3 3.72 1,373.4 1,694.8 3.48 1,377.1 1,686.2 3.21 1,380.2 1,678.7 2.94 1,383.2 1,672.0 2.71 1,386.2 1,665.8 2.52 1,389.2 1,660.3 2.21 1,392.2 1,655.0	33.88 1,313.0 1,964 24.50 1,314.4 1,800 19.83 1,340.4 1,760.3 14.06 1,354.4 1,746.2 12.96 1,359.4 1,730.8 11.96 1,363.9 1,718.8 10.96 1,368.4 1,704.1 4.24 1,372.0 1,691.6 4.15 1,375.7 1,704.3 3.72 1,379.4 1,694.8 3.48 1,383.1 1,686.2 3.21 1,386.2 1,678.7 2.94 1,389.2 1,672.0 2.71 1,392.2 1,665.8 2.52 1,395.2 1,660.3 2.21 1,398.2 1,655.0	34.47 1,319.0 1,974 25.15 1,316.4 1,800 20.44 1,346.4 1,760.3 14.61 1,360.4 1,746.2 13.41 1,365.4 1,730.8 12.41 1,369.9 1,718.8 11.41 1,374.4 1,704.1 4.71 1,378.0 1,691.6 4.15 1,381.7 1,704.3 3.72 1,385.4 1,694.8 3.48 1,389.1 1,686.2 3.21 1,392.2 1,678.7 2.94 1,395.2 1,672.0 2.71 1,398.2 1,665.8 2.52 1,401.2 1,660.3 2.21 1,404.2 1,655.0	35.06 1,325.0 1,984 25.80 1,322.4 1,800 21.04 1,352.4 1,760.3 15.16 1,366.4 1,746.2 13.96 1,371.4 1,730.8 12.96 1,375.9 1,718.8 11.96 1,380.4 1,704.1 4.24 1,384.0 1,691.6 4.15 1,387.7 1,704.3 3.72 1,391.4 1,694.8 3.48 1,395.1 1,686.2 3.21 1,398.2 1,678.7 2.94 1,401.2 1,672.0 2.71 1,404.2 1,665.8 2.52 1,407.2 1,660.3 2.21 1,410.2 1,655.0	35.65 1,331.0 1,994 26.45 1,328.4 1,800 21.63 1,358.4 1,760.3 15.71 1,372.4 1,746.2 14.41 1,377.4 1,730.8 13.41 1,381.9 1,718.8 12.41 1,386.4 1,704.1 4.71 1,390.0 1,691.6 4.15 1,393.7 1,704.3 3.72 1,397.4 1,694.8 3.48 1,401.1 1,686.2 3.21 1,404.2 1,678.7 2.94 1,407.2 1,672.0 2.71 1,410.2 1,665.8 2.52 1,413.2 1,660.3 2.21 1,416.2 1,655.0	36.24 1,337.0 2,004 27.10 1,334.4 1,800 22.24 1,364.4 1,760.3 16.26 1,378.4 1,746.2 14.96 1,383.4 1,730.8 13.96 1,387.9 1,718.8 12.96 1,392.4 1,704.1 4.24 1,396.0 1,691.6 4.15 1,399.7 1,704.3 3.72 1,403.4 1,694.8 3.48 1,407.1 1,686.2 3.21 1,410.2 1,678.7 2.94 1,413.2 1,672.0 2.71 1,416.2 1,665.8 2.52 1,419.2 1,660.3 2.21 1,422.2 1,655.0	36.83 1,343.0 2,014 27.75 1,340.4 1,800 22.83 1,370.4 1,760.3 16.81 1,382.4 1,746.2 15.41 1,387.4 1,730.8 14.41 1,391.9 1,718.8 13.41 1,396.4 1,704.1 4.71 1,400.0 1,691.6 4.15 1,403.7 1,704.3 3.72 1,407.4 1,694.8 3.48 1,411.1 1,686.2 3.21 1,414.2 1,678.7 2.94 1,417.2 1,672.0 2.71 1,420.2 1,665.8 2.52 1,423.2 1,660.3 2.21 1,426.2 1,655.0	37.42 1,349.0 2,024 28.40 1,346.4 1,800 23.44 1,376.4 1,760.3 17.36 1,386.4 1,746.2 15.96 1,391.4 1,730.8 14.96 1,395.9 1,718.8 13.96 1,400.4 1,704.1 4.24 1,404.0 1,691.6 4.15 1,407.7 1,704.3 3.72 1,411.4 1,694.8 3.48 1,415.1 1,686.2 3.21 1,418.2 1,678.7 2.94 1,421.2 1,672.0 2.71 1,424.2 1,665.8 2.52 1,427.2 1,660.3 2.21 1,430.2 1,655.0	38.01 1,355.0 2,034 29.05 1,352.4 1,800 24.03 1,382.4 1,760.3 17.91 1,392.4 1,746.2 16.46 1,397.4 1,730.8 15.46 1,401.9 1,718.8 14.46 1,406.4 1,704.1 4.71 1,410.0 1,691.6 4.15 1,413.7 1,704.3 3.72 1,417.4 1,694.8 3.48 1,421.1 1,686.2 3.21 1,424.2 1,678.7 2.94 1,427.2 1,672.0 2.71 1,430.2 1,665.8 2.52 1,433.2 1,660.3 2.21 1,436.2 1,655.0	38.60 1,361.0 2,044 29.70 1,358.4 1,800 24.63 1,388.4 1,760.3 18.46 1,398.4 1,746.2 17.01 1,403.4 1,730.8 15.96 1,407.9 1,718.8 14.96 1,412.4 1,704.1 4.24 1,416.0 1,691.6 4.15 1,419.7 1,704.3 3.72 1,423.4 1,694.8 3.48 1,427.1 1,686.2 3.21 1,430.2 1,678.7 2.94 1,433.2 1,672.0 2.71 1,436.2 1,665.8 2.52 1,439.2 1,660.3 2.21 1,442.2 1,655.0	39.19 1,367.0 2,054 30.35 1,364.4 1,800 25.23 1,394.4 1,760.3 19.01 1,404.4 1,746.2 17.56 1,409.4 1,730.8 16.46 1,413.9 1,718.8 15.46 1,418.4 1,704.1 4.71 1,422.0 1,691.6 4.15 1,425.7 1,704.3 3.72 1,429.4 1,694.8 3.48 1,433.1 1,686.2 3.21 1,436

TABLE II B.

TEMPERATURE OF FIRE WHEN BURNING PURE CARBON WITH VARYING AMOUNTS OF AIR.

Heating value of carbon burned to CO_2 , 14,600 B. T. U. per pound.Heating value of carbon burned to CO , 4,450 B. T. U. per pound.

Specific heat of gases of combustion in either case, .24.

Formula: Elevation of temperature in degrees Fahr.=

B. T. U. generated by combustion

Weight of gases $\times$ specific heat of gasesTo burn 1 pound of C to CO_2 with no excess of air requires 11.52 pounds of air, making 12.52 pounds of gas.To burn 1 pound of C to CO with no excess of air requires 5.76 pounds of air, making 6.76 pounds of gas.

PART I.—TEMPERATURES OF FIRE WITH AN INSUFFICIENT AMOUNT OF AIR.

Percentage of air below 11.52.....	0.0	10	20	30	40	50
Air per lb. of C.....	11.52	10.87	9.22	8.06	6.95	5.76
Air plus C per lb. of C=lbs. of gas.....	12.52	11.37	10.22	9.06	7.95	6.76
Percentage of C burned to CO_2	100	80	60	40	20	0.0
Percentage of C burned to CO	0.0	20	40	60	80	100
Heat (B.T.U.) generated in making CO_2 ...	14,600	11,680	8,760	5,840	2,920	0.0
Heat (B.T.U.) generated in making CO	0.0	890	1,780	2,670	3,560	4,450
Total heat generated.....	14,600	12,570	10,540	8,510	6,480	4,450
Elevation of the temperature of the fire...	4,860	4,606	4,238	3,914	3,418	2,743

PART II.—TEMPERATURES OF FIRE WITH AN EXCESS OF AIR. ALL C BURNED TO CO_2 .

Percentage of air above 11.52 lbs. per lb. of C	25	50	75	100	150	200
Lbs. of air per lb. of carbon	14.40	17.28	20.16	23.04	28.80	34.56
Lbs. of air plus C per lb. of C = lbs. of gas	15.40	18.28	21.16	23.04	28.80	35.56
Percentage of C burned to CO_2	100	100	100	100	100	100
Heat (B.T.U.) generated in making CO_2 ...	14,600	14,600	14,600	14,600	14,600	14,600
Elevation of the temperature of the fire...	3,950	3,328	2,875	2,530	2,041	1,711

NOTE.—The temperatures of the fire given above are theoretical and are based on the assumption that there is no loss by radiation, convection or otherwise. They are never attained in practice, since the losses mentioned above are always present.

TABLE III.

SPECIFIC HEATS OF SOME GASES.

Substance.	Temperature range in degrees C.	Mean specific heat at constant pressure.
Air	20-440	.2366
	20-800	.2430
Carbon dioxide (CO ₂).....	15-100	.2025
	11-214	.2169
Carbon monoxide (CO).....	26-198	.2426
Hydrogen	21-100	3.4100
Nitrogen	20-440	.2419
Oxygen	20-440	.2240
Sulphur dioxide (SO ₂).....	16-202	.1544
Water vapor	100	.421
	180	.51

TABLE IV.

SPECIFIC HEATS OF SOME LIQUIDS.

Substance.	Temperature range in degrees C.	Specific heat.
Alcohol	0	.548
(Methyl)	40	.648
Glycerine	15-50	.576
Oils—castor	20	.434
Turpentine	0	.411
Petroleum	21-58	.511

TABLE V.

SPECIFIC HEATS OF SOME SOLIDS.

Substance.	Temperature range in degrees C.	Specific heat.
Carbon—graphite	11	.16
Copper	17	.0924
Iron, cast	20-100	.1189
Iron, wrought	15-100	.1152
Lead	15	.0299
Mercury	85	.0328
Nickel	100	.1128

TABLES

TABLE VI.—TEMPERATURE CORRECTIONS TO READINGS OF SPECIFIC GRAVITY HYDROMETERS IN AMERICAN PETROLEUM OILS AT VARIOUS TEMPERATURES.

Observed temperature in ° F.	Observed specific gravity									
	0.900	0.901	0.902	0.903	0.904	0.905	0.906	0.907	0.908	0.909
	Corresponding specific gravities at 60°/60° F.									
30.....	.8893	.8903	.8913	.8923	.8933	.8943	.8953	.8963	.8973	.8983
31.....	.8896	.8906	.8916	.8926	.8936	.8947	.8957	.8967	.8977	.8987
32.....	.8900	.8910	.8920	.8930	.8940	.8950	.8960	.8970	.8980	.8990
33.....	.8903	.8913	.8923	.8933	.8943	.8954	.8964	.8974	.8984	.8994
34.....	.8907	.8917	.8927	.8937	.8947	.8957	.8967	.8977	.8987	.8997
35.....	.8911	.8921	.8931	.8941	.8951	.8961	.8971	.8981	.8991	.9001
36.....	.8915	.8925	.8935	.8945	.8955	.8965	.8975	.8985	.8995	.9005
37.....	.8918	.8928	.8938	.8948	.8958	.8968	.8978	.8988	.8998	.9008
38.....	.8922	.8932	.8942	.8952	.8962	.8972	.8982	.8992	.9002	.9012
39.....	.8925	.8935	.8945	.8955	.8965	.8975	.8985	.8995	.9005	.9015
40.....	.8929	.8939	.8949	.8959	.8969	.8979	.8989	.8999	.9009	.9019
41.....	.8932	.8942	.8952	.8962	.8972	.8982	.8992	.9002	.9012	.9022
42.....	.8936	.8946	.8956	.8966	.8976	.8986	.8996	.9006	.9016	.9026
43.....	.8940	.8950	.8960	.8970	.8980	.8990	.9000	.9010	.9020	.9030
44.....	.8943	.8953	.8963	.8973	.8983	.8993	.9003	.9013	.9023	.9033
45.....	.8947	.8957	.8967	.8977	.8987	.8997	.9007	.9017	.9027	.9037
46.....	.8950	.8960	.8970	.8980	.8990	.9000	.9010	.9020	.9030	.9040
47.....	.8954	.8964	.8974	.8984	.8994	.9004	.9014	.9024	.9034	.9044
48.....	.8957	.8967	.8977	.8987	.8997	.9007	.9017	.9027	.9037	.9047
49.....	.8961	.8971	.8981	.8991	.9001	.9011	.9021	.9031	.9041	.9051
50.....	.8964	.8974	.8984	.8994	.9004	.9014	.9024	.9034	.9044	.9054
51.....	.8968	.8978	.8988	.8998	.9008	.9018	.9028	.9038	.9048	.9058
52.....	.8972	.8982	.8992	.9002	.9012	.9022	.9032	.9042	.9052	.9062
53.....	.8975	.8985	.8995	.9005	.9015	.9025	.9035	.9045	.9055	.9065
54.....	.8979	.8989	.8999	.9009	.9019	.9029	.9039	.9049	.9059	.9069
55.....	.8982	.8992	.9002	.9012	.9022	.9032	.9042	.9052	.9062	.9072
56.....	.8986	.8996	.9006	.9016	.9026	.9036	.9046	.9056	.9066	.9076
57.....	.8990	.9000	.9010	.9020	.9030	.9040	.9050	.9060	.9070	.9080
58.....	.8993	.9003	.9013	.9023	.9033	.9043	.9053	.9063	.9073	.9083
59.....	.8997	.9007	.9017	.9027	.9037	.9047	.9057	.9067	.9077	.9087
60.....	.9000	.9010	.9020	.9030	.9040	.9050	.9060	.9070	.9080	.9090
61.....	.9004	.9014	.9024	.9034	.9044	.9054	.9064	.9074	.9084	.9094
62.....	.9007	.9017	.9027	.9037	.9047	.9057	.9067	.9077	.9087	.9097
63.....	.9010	.9020	.9030	.9040	.9050	.9060	.9070	.9080	.9090	.9100
64.....	.9014	.9024	.9034	.9044	.9054	.9064	.9074	.9084	.9094	.9104
65.....	.9018	.9028	.9038	.9048	.9058	.9068	.9078	.9088	.9098	.9108
66.....	.9022	.9032	.9042	.9052	.9062	.9071	.9081	.9091	.9101	.9111
67.....	.9025	.9035	.9045	.9055	.9065	.9075	.9085	.9095	.9105	.9115
68.....	.9029	.9039	.9049	.9059	.9069	.9078	.9088	.9098	.9108	.9118
69.....	.9032	.9042	.9052	.9062	.9072	.9082	.9092	.9102	.9112	.9122
70.....	.9036	.9046	.9056	.9066	.9076	.9086	.9096	.9106	.9116	.9126
71.....	.9039	.9049	.9059	.9069	.9079	.9089	.9099	.9109	.9119	.9129
72.....	.9043	.9053	.9063	.9073	.9083	.9093	.9103	.9113	.9123	.9133
73.....	.9047	.9057	.9067	.9077	.9087	.9097	.9107	.9117	.9127	.9137
74.....	.9050	.9060	.9070	.9080	.9090	.9100	.9110	.9120	.9130	.9140
75.....	.9054	.9064	.9074	.9084	.9094	.9104	.9114	.9124	.9134	.9144
76.....	.9057	.9067	.9077	.9087	.9097	.9107	.9117	.9127	.9137	.9147
77.....	.9060	.9070	.9080	.9090	.9100	.9110	.9120	.9130	.9140	.9150
78.....	.9064	.9074	.9084	.9094	.9104	.9114	.9124	.9134	.9144	.9154
79.....	.9068	.9078	.9088	.9098	.9108	.9118	.9128	.9138	.9148	.9158
80.....	.9072	.9082	.9092	.9102	.9112	.9121	.9131	.9141	.9151	.9161
81.....	.9075	.9085	.9095	.9105	.9115	.9125	.9135	.9145	.9155	.9165
82.....	.9079	.9089	.9099	.9109	.9119	.9129	.9139	.9149	.9159	.9169
83.....	.9082	.9092	.9102	.9112	.9122	.9132	.9142	.9152	.9162	.9172
84.....	.9085	.9095	.9105	.9115	.9125	.9135	.9145	.9155	.9165	.9175
85.....	.9089	.9099	.9109	.9119	.9129	.9139	.9149	.9159	.9169	.9179
86.....	.9092	.9102	.9112	.9122	.9132	.9142	.9152	.9162	.9172	.9182
87.....	.9096	.9106	.9116	.9126	.9136	.9146	.9156	.9166	.9176	.9186
88.....	.9099	.9109	.9119	.9129	.9139	.9149	.9159	.9169	.9179	.9189
89.....	.9103	.9113	.9123	.9133	.9143	.9153	.9163	.9173	.9183	.9193

TABLES

TABLE VI—TEMPERATURE CORRECTIONS TO READINGS OF SPECIFIC GRAVITY HYDROMETERS IN AMERICAN PETROLEUM OILS AT VARIOUS TEMPERATURES.—*Continued*

Observed temperature in ° F.	Observed specific gravity									
	0.900	0.901	0.902	0.903	0.904	0.905	0.906	0.907	0.908	0.909
	Corresponding specific gravities at 60°/60° F.									
90.....	.9106	.9116	.9126	.9136	.9146	.9156	.9166	.9176	.9186	.9196
91.....	.9110	.9120	.9130	.9140	.9150	.9160	.9170	.9180	.9190	.9200
92.....	.9114	.9124	.9134	.9144	.9154	.9164	.9174	.9184	.9194	.9204
93.....	.9117	.9127	.9137	.9147	.9157	.9167	.9177	.9187	.9197	.9207
94.....	.9120	.9130	.9140	.9150	.9160	.9170	.9180	.9190	.9200	.9210
95.....	.9124	.9134	.9144	.9154	.9164	.9173	.9183	.9193	.9203	.9213
96.....	.9127	.9137	.9147	.9157	.9167	.9177	.9187	.9197	.9207	.9217
97.....	.9131	.9141	.9151	.9161	.9171	.9180	.9190	.9200	.9210	.9220
98.....	.9135	.9145	.9155	.9165	.9175	.9184	.9194	.9204	.9214	.9224
99.....	.9138	.9148	.9158	.9168	.9178	.9187	.9197	.9207	.9217	.9227
100.....	.9141	.9151	.9161	.9171	.9181	.9191	.9201	.9211	.9221	.9231
101.....	.9144	.9154	.9164	.9174	.9184	.9194	.9204	.9214	.9224	.9234
102.....	.9148	.9158	.9168	.9178	.9188	.9197	.9207	.9217	.9227	.9237
103.....	.9151	.9161	.9171	.9181	.9191	.9201	.9211	.9221	.9231	.9241
104.....	.9155	.9165	.9175	.9185	.9195	.9205	.9215	.9225	.9235	.9245
105.....	.9159	.9169	.9179	.9189	.9199	.9208	.9218	.9228	.9238	.9248
106.....	.9162	.9172	.9182	.9192	.9202	.9211	.9221	.9231	.9241	.9251
107.....	.9165	.9175	.9185	.9195	.9205	.9214	.9224	.9234	.9244	.9254
108.....	.9169	.9179	.9189	.9199	.9209	.9218	.9228	.9238	.9248	.9258
109.....	.9173	.9183	.9193	.9203	.9213	.9222	.9232	.9242	.9252	.9262
110.....	.9176	.9186	.9196	.9206	.9216	.9225	.9235	.9245	.9255	.9265
111.....	.9179	.9189	.9199	.9209	.9219	.9228	.9238	.9248	.9258	.9268
112.....	.9183	.9193	.9203	.9213	.9223	.9232	.9242	.9252	.9262	.9272
113.....	.9186	.9196	.9206	.9216	.9226	.9236	.9246	.9256	.9266	.9276
114.....	.9189	.9199	.9209	.9219	.9229	.9239	.9249	.9259	.9269	.9279
115.....	.9193	.9203	.9213	.9223	.9233	.9242	.9252	.9262	.9272	.9282
116.....	.9196	.9206	.9216	.9226	.9236	.9245	.9255	.9265	.9275	.9285
117.....	.9199	.9209	.9219	.9229	.9239	.9248	.9258	.9268	.9278	.9288
118.....	.9202	.9212	.9222	.9232	.9242	.9252	.9262	.9272	.9282	.9292
119.....	.9206	.9216	.9226	.9236	.9246	.9255	.9265	.9275	.9285	.9295

Observed temperature in ° F.	Observed specific gravity									
	0.9100	0.9101	0.9102	0.9103	0.9104	0.9105	0.9106	0.9107	0.9108	0.9109
	Corresponding specific gravities at 60°/60° F.									
30.....	.9063	.9063	.9013	.9023	.9033	.9043	.9053	.9063	.9073	.9083
31.....	.9067	.9067	.9017	.9027	.9037	.9047	.9057	.9067	.9077	.9087
32.....	.9069	.9010	.9020	.9030	.9040	.9050	.9060	.9070	.9080	.9090
33.....	.9064	.9014	.9024	.9034	.9044	.9054	.9064	.9074	.9084	.9094
34.....	.9067	.9017	.9027	.9037	.9047	.9057	.9067	.9077	.9087	.9097
35.....	.9011	.9021	.9031	.9041	.9051	.9061	.9071	.9081	.9091	.9101
36.....	.9015	.9025	.9035	.9045	.9055	.9065	.9075	.9085	.9095	.9105
37.....	.9018	.9028	.9038	.9048	.9058	.9068	.9078	.9088	.9098	.9108
38.....	.9022	.9032	.9042	.9052	.9062	.9072	.9082	.9092	.9102	.9112
39.....	.9025	.9035	.9045	.9055	.9065	.9075	.9085	.9095	.9105	.9115
40.....	.9029	.9039	.9049	.9059	.9069	.9079	.9089	.9099	.9109	.9119
41.....	.9032	.9042	.9052	.9062	.9072	.9082	.9092	.9102	.9112	.9122
42.....	.9036	.9046	.9056	.9066	.9076	.9086	.9096	.9106	.9116	.9126
43.....	.9040	.9050	.9060	.9070	.9080	.9090	.9100	.9110	.9120	.9130
44.....	.9043	.9053	.9063	.9073	.9083	.9093	.9103	.9113	.9123	.9133
45.....	.9047	.9057	.9067	.9077	.9087	.9097	.9107	.9117	.9127	.9137
46.....	.9050	.9060	.9070	.9080	.9090	.9100	.9110	.9120	.9130	.9140
47.....	.9054	.9064	.9074	.9084	.9094	.9104	.9114	.9124	.9134	.9144
48.....	.9057	.9067	.9077	.9087	.9097	.9107	.9117	.9127	.9137	.9147
49.....	.9061	.9071	.9081	.9091	.9101	.9111	.9121	.9131	.9141	.9151
50.....	.9064	.9074	.9084	.9094	.9104	.9114	.9124	.9134	.9144	.9154
51.....	.9068	.9078	.9088	.9098	.9108	.9118	.9128	.9138	.9148	.9158
52.....	.9072	.9082	.9092	.9102	.9112	.9122	.9132	.9142	.9152	.9162
53.....	.9075	.9085	.9095	.9105	.9115	.9125	.9135	.9145	.9155	.9165
54.....	.9079	.9089	.9099	.9109	.9119	.9129	.9139	.9149	.9159	.9169

TABLES

TABLE VI.—TEMPERATURE CORRECTIONS TO READINGS OF SPECIFIC GRAVITY HYDROMETERS IN AMERICAN PETROLEUM OILS AT VARIOUS TEMPERATURES.—*Continued.*

Observed temperature in ° F.	Observed specific gravity									
	0.9100	0.9101	0.9102	0.9103	0.9104	0.9105	0.9106	0.9107	0.9108	0.9109
	Corresponding specific gravities at 60°/60° F.									
55.....	.9082	.9092	.9102	.9112	.9122	.9132	.9142	.9152	.9162	.9172
56.....	.9086	.9096	.9106	.9116	.9126	.9136	.9146	.9156	.9166	.9176
57.....	.9090	.9100	.9110	.9120	.9130	.9140	.9150	.9160	.9170	.9180
58.....	.9093	.9103	.9113	.9123	.9133	.9143	.9153	.9163	.9173	.9183
59.....	.9097	.9107	.9117	.9127	.9137	.9147	.9157	.9167	.9177	.9187
60.....	.9100	.9110	.9120	.9130	.9140	.9150	.9160	.9170	.9180	.9190
61.....	.9104	.9114	.9124	.9134	.9144	.9154	.9164	.9174	.9184	.9194
62.....	.9107	.9117	.9127	.9137	.9147	.9157	.9167	.9177	.9187	.9197
63.....	.9110	.9120	.9130	.9140	.9150	.9160	.9170	.9180	.9190	.9200
64.....	.9114	.9124	.9134	.9144	.9154	.9164	.9174	.9184	.9194	.9204
65.....	.9118	.9128	.9138	.9148	.9158	.9168	.9178	.9188	.9198	.9208
66.....	.9121	.9131	.9141	.9151	.9161	.9171	.9181	.9191	.9201	.9211
67.....	.9125	.9135	.9145	.9155	.9165	.9175	.9185	.9195	.9205	.9215
68.....	.9128	.9138	.9148	.9158	.9168	.9178	.9188	.9198	.9208	.9218
69.....	.9132	.9142	.9152	.9162	.9172	.9182	.9192	.9202	.9212	.9222
70.....	.9136	.9146	.9156	.9166	.9176	.9185	.9195	.9205	.9215	.9225
71.....	.9139	.9149	.9159	.9169	.9179	.9189	.9199	.9209	.9219	.9229
72.....	.9143	.9153	.9163	.9173	.9183	.9192	.9202	.9212	.9222	.9232
73.....	.9147	.9157	.9167	.9177	.9187	.9196	.9206	.9216	.9226	.9236
74.....	.9150	.9160	.9170	.9180	.9190	.9200	.9210	.9220	.9230	.9240
75.....	.9154	.9164	.9174	.9184	.9194	.9203	.9213	.9223	.9233	.9243
76.....	.9157	.9167	.9177	.9187	.9197	.9207	.9217	.9227	.9237	.9247
77.....	.9160	.9170	.9180	.9190	.9200	.9210	.9220	.9230	.9240	.9250
78.....	.9164	.9174	.9184	.9194	.9204	.9214	.9224	.9234	.9244	.9254
79.....	.9168	.9178	.9188	.9198	.9208	.9218	.9228	.9238	.9248	.9258
80.....	.9171	.9181	.9191	.9201	.9211	.9221	.9231	.9241	.9251	.9261
81.....	.9175	.9185	.9195	.9205	.9215	.9225	.9235	.9245	.9255	.9265
82.....	.9179	.9189	.9199	.9209	.9219	.9229	.9239	.9249	.9259	.9269
83.....	.9182	.9192	.9202	.9212	.9222	.9232	.9242	.9252	.9262	.9272
84.....	.9185	.9195	.9205	.9215	.9225	.9235	.9245	.9255	.9265	.9275
85.....	.9189	.9199	.9209	.9219	.9229	.9239	.9249	.9259	.9269	.9279
86.....	.9192	.9202	.9212	.9222	.9232	.9242	.9252	.9262	.9272	.9282
87.....	.9196	.9206	.9216	.9226	.9236	.9246	.9256	.9266	.9276	.9286
88.....	.9199	.9209	.9219	.9229	.9239	.9249	.9259	.9269	.9279	.9289
89.....	.9208	.9213	.9223	.9233	.9243	.9253	.9263	.9273	.9283	.9293
90.....	.9206	.9216	.9226	.9236	.9246	.9256	.9266	.9276	.9286	.9296
91.....	.9210	.9220	.9230	.9240	.9250	.9260	.9270	.9280	.9290	.9300
92.....	.9214	.9224	.9234	.9244	.9254	.9264	.9274	.9284	.9294	.9304
93.....	.9217	.9227	.9237	.9247	.9257	.9267	.9277	.9287	.9297	.9307
94.....	.9220	.9230	.9240	.9250	.9260	.9270	.9280	.9290	.9300	.9310
95.....	.9223	.9233	.9243	.9253	.9263	.9273	.9283	.9293	.9303	.9313
96.....	.9227	.9237	.9247	.9257	.9267	.9277	.9287	.9297	.9307	.9317
97.....	.9230	.9240	.9250	.9260	.9270	.9280	.9290	.9300	.9310	.9320
98.....	.9234	.9244	.9254	.9264	.9274	.9284	.9294	.9304	.9314	.9324
99.....	.9237	.9247	.9257	.9267	.9277	.9287	.9297	.9307	.9317	.9327
100.....	.9241	.9251	.9261	.9271	.9281	.9290	.9300	.9310	.9320	.9330
101.....	.9244	.9254	.9264	.9274	.9284	.9294	.9304	.9314	.9324	.9334
102.....	.9247	.9257	.9267	.9277	.9287	.9297	.9307	.9317	.9327	.9337
103.....	.9251	.9261	.9271	.9281	.9291	.9301	.9311	.9321	.9331	.9341
104.....	.9255	.9265	.9275	.9285	.9295	.9304	.9314	.9324	.9334	.9344
105.....	.9258	.9268	.9278	.9288	.9298	.9307	.9317	.9327	.9337	.9347
106.....	.9261	.9271	.9281	.9291	.9301	.9310	.9320	.9330	.9340	.9350
107.....	.9264	.9274	.9284	.9294	.9304	.9313	.9323	.9333	.9343	.9353
108.....	.9268	.9278	.9288	.9298	.9308	.9317	.9327	.9337	.9347	.9357
109.....	.9272	.9282	.9292	.9302	.9312	.9321	.9331	.9341	.9351	.9361
110.....	.9275	.9285	.9295	.9305	.9315	.9324	.9334	.9344	.9354	.9364
111.....	.9278	.9288	.9298	.9308	.9318	.9327	.9337	.9347	.9357	.9367
112.....	.9282	.9292	.9302	.9312	.9322	.9331	.9341	.9351	.9361	.9371
113.....	.9286	.9296	.9306	.9316	.9326	.9335	.9345	.9355	.9365	.9375
114.....	.9289	.9299	.9309	.9319	.9329	.9338	.9348	.9358	.9368	.9378
115.....	.9292	.9302	.9312	.9322	.9332	.9341	.9351	.9361	.9371	.9381
116.....	.9295	.9305	.9315	.9325	.9335	.9344	.9354	.9364	.9374	.9384
117.....	.9298	.9308	.9318	.9328	.9338	.9347	.9357	.9367	.9377	.9387
118.....	.9302	.9312	.9322	.9332	.9342	.9351	.9361	.9371	.9381	.9391
119.....	.9305	.9315	.9325	.9335	.9345	.9354	.9364	.9374	.9384	.9394

TABLES

TABLE VI.—TEMPERATURE CORRECTIONS TO READINGS OF SPECIFIC GRAVITY HYDROMETERS IN AMERICAN PETROLEUM OILS AT VARIOUS TEMPERATURES.—*Continued.*

Observed temperature in ° F.	Observed specific gravity									
	0.920	0.921	0.922	0.923	0.924	0.925	0.926	0.927	0.928	0.929
	Corresponding specific gravities at 60°/60° F									
30.....	.9093	.9103	.9113	.9123	.9133	.9143	.9153	.9163	.9173	.9183
31.....	.9097	.9107	.9117	.9127	.9137	.9147	.9157	.9167	.9177	.9187
32.....	.9100	.9110	.9120	.9130	.9140	.9150	.9160	.9170	.9180	.9190
33.....	.9104	.9114	.9124	.9134	.9144	.9154	.9164	.9174	.9184	.9194
34.....	.9107	.9117	.9127	.9137	.9147	.9157	.9167	.9177	.9187	.9197
35.....	.9111	.9121	.9131	.9141	.9151	.9161	.9171	.9181	.9191	.9201
36.....	.9114	.9124	.9134	.9144	.9154	.9164	.9174	.9184	.9194	.9204
37.....	.9118	.9128	.9138	.9148	.9158	.9168	.9178	.9188	.9198	.9208
38.....	.9122	.9132	.9142	.9152	.9162	.9172	.9182	.9192	.9202	.9212
39.....	.9125	.9135	.9145	.9155	.9165	.9175	.9185	.9195	.9205	.9215
40.....	.9129	.9139	.9149	.9159	.9169	.9179	.9189	.9199	.9209	.9219
41.....	.9132	.9142	.9152	.9162	.9172	.9182	.9192	.9202	.9212	.9222
42.....	.9136	.9146	.9156	.9166	.9176	.9186	.9196	.9206	.9216	.9226
43.....	.9140	.9150	.9160	.9170	.9180	.9190	.9200	.9210	.9220	.9230
44.....	.9143	.9153	.9163	.9173	.9183	.9193	.9203	.9213	.9223	.9233
45.....	.9147	.9157	.9167	.9177	.9187	.9197	.9207	.9217	.9227	.9237
46.....	.9150	.9160	.9170	.9180	.9190	.9200	.9210	.9220	.9230	.9240
47.....	.9154	.9164	.9174	.9184	.9194	.9204	.9214	.9224	.9234	.9244
48.....	.9157	.9167	.9177	.9187	.9197	.9207	.9217	.9227	.9237	.9247
49.....	.9161	.9171	.9181	.9191	.9201	.9211	.9221	.9231	.9241	.9251
50.....	.9164	.9174	.9184	.9194	.9204	.9214	.9224	.9234	.9244	.9254
51.....	.9168	.9178	.9188	.9198	.9208	.9218	.9228	.9238	.9248	.9258
52.....	.9172	.9182	.9192	.9202	.9212	.9222	.9232	.9242	.9252	.9262
53.....	.9175	.9185	.9195	.9205	.9215	.9225	.9235	.9245	.9255	.9265
54.....	.9179	.9189	.9199	.9209	.9219	.9229	.9239	.9249	.9259	.9269
55.....	.9182	.9192	.9202	.9212	.9222	.9232	.9242	.9252	.9262	.9272
56.....	.9186	.9196	.9206	.9216	.9226	.9236	.9246	.9256	.9266	.9276
57.....	.9190	.9200	.9210	.9220	.9230	.9240	.9250	.9260	.9270	.9280
58.....	.9193	.9203	.9213	.9223	.9233	.9243	.9253	.9263	.9273	.9283
59.....	.9197	.9207	.9217	.9227	.9237	.9247	.9257	.9267	.9277	.9287
60.....	.9200	.9210	.9220	.9230	.9240	.9250	.9260	.9270	.9280	.9290
61.....	.9204	.9214	.9224	.9234	.9244	.9254	.9264	.9274	.9284	.9294
62.....	.9207	.9217	.9227	.9237	.9247	.9257	.9267	.9277	.9287	.9297
63.....	.9210	.9220	.9230	.9240	.9250	.9260	.9270	.9280	.9290	.9300
64.....	.9214	.9224	.9234	.9244	.9254	.9264	.9274	.9284	.9294	.9304
65.....	.9218	.9228	.9238	.9248	.9258	.9268	.9278	.9288	.9298	.9308
66.....	.9221	.9231	.9241	.9251	.9261	.9271	.9281	.9291	.9301	.9311
67.....	.9225	.9235	.9245	.9255	.9265	.9275	.9285	.9295	.9305	.9315
68.....	.9228	.9238	.9248	.9258	.9268	.9278	.9288	.9298	.9308	.9318
69.....	.9232	.9242	.9252	.9262	.9272	.9282	.9292	.9302	.9312	.9322
70.....	.9235	.9245	.9255	.9265	.9275	.9285	.9295	.9305	.9315	.9325
71.....	.9239	.9249	.9259	.9269	.9279	.9289	.9299	.9309	.9319	.9329
72.....	.9242	.9252	.9262	.9272	.9282	.9292	.9302	.9312	.9322	.9332
73.....	.9246	.9256	.9266	.9276	.9286	.9296	.9306	.9316	.9326	.9336
74.....	.9250	.9260	.9270	.9280	.9290	.9300	.9310	.9320	.9330	.9340
75.....	.9253	.9263	.9273	.9283	.9293	.9303	.9313	.9323	.9333	.9343
76.....	.9257	.9267	.9277	.9287	.9297	.9307	.9317	.9327	.9337	.9347
77.....	.9260	.9270	.9280	.9290	.9300	.9310	.9320	.9330	.9340	.9350
78.....	.9264	.9274	.9284	.9294	.9304	.9314	.9324	.9334	.9344	.9354
79.....	.9268	.9278	.9288	.9298	.9308	.9317	.9327	.9337	.9347	.9357
80.....	.9271	.9281	.9291	.9301	.9311	.9320	.9330	.9340	.9350	.9360
81.....	.9275	.9285	.9295	.9305	.9315	.9324	.9334	.9344	.9354	.9364
82.....	.9279	.9289	.9299	.9309	.9319	.9328	.9338	.9348	.9358	.9368
83.....	.9282	.9292	.9302	.9312	.9322	.9331	.9341	.9351	.9361	.9371
84.....	.9285	.9295	.9305	.9315	.9325	.9335	.9345	.9355	.9365	.9375
85.....	.9289	.9299	.9309	.9319	.9329	.9339	.9349	.9359	.9369	.9379
86.....	.9292	.9302	.9312	.9322	.9332	.9342	.9352	.9362	.9372	.9382
87.....	.9296	.9306	.9316	.9326	.9336	.9346	.9356	.9366	.9376	.9386
88.....	.9299	.9309	.9319	.9329	.9339	.9349	.9359	.9369	.9379	.9389
89.....	.9303	.9313	.9323	.9333	.9343	.9353	.9363	.9373	.9383	.9393

TABLES

TABLE VI.—TEMPERATURE CORRECTIONS TO READINGS OF SPECIFIC GRAVITY HYDROMETERS IN AMERICAN PETROLEUM OILS AT VARIOUS TEMPERATURES.—*Continued.*

Observed temperature in ° F.	Observed specific gravity									
	0.920	0.921	0.922	0.923	0.924	0.925	0.926	0.927	0.928	0.929
	Corresponding specific gravities at 60°/60° F.									
90.....	.9306	.9316	.9326	.9336	.9346	.9356	.9366	.9376	.9386	.9396
91.....	.9310	.9320	.9330	.9340	.9350	.9360	.9370	.9380	.9390	.9400
92.....	.9314	.9324	.9334	.9344	.9354	.9363	.9373	.9383	.9393	.9403
93.....	.9317	.9327	.9337	.9347	.9357	.9367	.9377	.9387	.9397	.9407
94.....	.9320	.9330	.9340	.9350	.9360	.9370	.9380	.9390	.9400	.9410
95.....	.9323	.9333	.9343	.9353	.9363	.9373	.9383	.9393	.9403	.9413
96.....	.9327	.9337	.9347	.9357	.9367	.9377	.9387	.9397	.9407	.9417
97.....	.9330	.9340	.9350	.9360	.9370	.9380	.9390	.9400	.9410	.9420
98.....	.9334	.9344	.9354	.9364	.9374	.9384	.9394	.9404	.9414	.9424
99.....	.9337	.9347	.9357	.9367	.9377	.9387	.9397	.9407	.9417	.9427
100.....	.9340	.9350	.9360	.9370	.9380	.9390	.9400	.9410	.9420	.9430
101.....	.9344	.9354	.9364	.9374	.9384	.9394	.9404	.9414	.9424	.9434
102.....	.9347	.9357	.9367	.9377	.9387	.9397	.9407	.9417	.9427	.9437
103.....	.9351	.9361	.9371	.9381	.9391	.9400	.9410	.9420	.9430	.9440
104.....	.9354	.9364	.9374	.9384	.9394	.9404	.9414	.9424	.9434	.9444
105.....	.9357	.9367	.9377	.9387	.9397	.9407	.9417	.9427	.9437	.9447
106.....	.9360	.9370	.9380	.9390	.9400	.9410	.9420	.9430	.9440	.9450
107.....	.9363	.9373	.9383	.9393	.9403	.9413	.9423	.9433	.9443	.9453
108.....	.9367	.9377	.9387	.9397	.9407	.9417	.9427	.9437	.9447	.9457
109.....	.9371	.9381	.9391	.9401	.9411	.9420	.9430	.9440	.9450	.9460
110.....	.9374	.9384	.9394	.9404	.9414	.9424	.9434	.9444	.9454	.9464
111.....	.9377	.9387	.9397	.9407	.9417	.9427	.9437	.9447	.9457	.9467
112.....	.9381	.9391	.9401	.9411	.9421	.9431	.9441	.9451	.9461	.9471
113.....	.9385	.9395	.9405	.9415	.9425	.9435	.9445	.9455	.9465	.9475
114.....	.9388	.9398	.9408	.9418	.9428	.9438	.9448	.9458	.9468	.9478
115.....	.9391	.9401	.9411	.9421	.9431	.9441	.9451	.9461	.9471	.9481
116.....	.9394	.9404	.9414	.9424	.9434	.9444	.9454	.9464	.9474	.9484
117.....	.9397	.9407	.9417	.9427	.9437	.9447	.9457	.9467	.9477	.9487
118.....	.9401	.9411	.9421	.9431	.9441	.9450	.9460	.9470	.9480	.9490
119.....	.9404	.9414	.9424	.9434	.9444	.9454	.9464	.9474	.9484	.9494
Observed temperature in ° F.	Observed specific gravity									
	0.930	0.931	0.932	0.933	0.934	0.935	0.936	0.937	0.938	0.939
	Corresponding specific gravities at 60°/60° F.									
30.....	.9193	.9203	.9213	.9223	.9233	.9243	.9253	.9263	.9273	.9283
31.....	.9197	.9207	.9217	.9227	.9237	.9247	.9257	.9267	.9277	.9287
32.....	.9200	.9210	.9220	.9230	.9240	.9250	.9260	.9270	.9280	.9290
33.....	.9204	.9214	.9224	.9234	.9244	.9254	.9264	.9274	.9284	.9294
34.....	.9207	.9217	.9227	.9237	.9247	.9257	.9267	.9277	.9287	.9297
35.....	.9211	.9221	.9231	.9241	.9251	.9261	.9271	.9281	.9291	.9301
36.....	.9214	.9224	.9234	.9244	.9254	.9264	.9274	.9284	.9294	.9304
37.....	.9218	.9228	.9238	.9248	.9258	.9268	.9278	.9288	.9298	.9308
38.....	.9222	.9232	.9242	.9252	.9262	.9272	.9282	.9292	.9302	.9312
39.....	.9225	.9235	.9245	.9255	.9265	.9275	.9285	.9295	.9305	.9315
40.....	.9229	.9239	.9249	.9259	.9269	.9277	.9289	.9299	.9309	.9319
41.....	.9232	.9242	.9252	.9262	.9272	.9282	.9292	.9302	.9312	.9322
42.....	.9236	.9246	.9256	.9266	.9276	.9286	.9296	.9306	.9316	.9326
43.....	.9240	.9250	.9260	.9270	.9280	.9290	.9300	.9310	.9320	.9330
44.....	.9243	.9253	.9263	.9273	.9283	.9293	.9303	.9313	.9323	.9333
45.....	.9247	.9257	.9267	.9277	.9287	.9297	.9307	.9317	.9327	.9337
46.....	.9250	.9260	.9270	.9280	.9290	.9300	.9310	.9320	.9330	.9340
47.....	.9254	.9264	.9274	.9284	.9294	.9304	.9314	.9324	.9334	.9344
48.....	.9257	.9267	.9277	.9287	.9297	.9307	.9317	.9327	.9337	.9347
49.....	.9261	.9271	.9281	.9291	.9301	.9311	.9321	.9331	.9341	.9351
50.....	.9264	.9274	.9284	.9294	.9304	.9315	.9325	.9335	.9345	.9355
51.....	.9268	.9278	.9288	.9298	.9308	.9318	.9328	.9338	.9348	.9358
52.....	.9272	.9282	.9292	.9302	.9312	.9322	.9332	.9342	.9352	.9362
53.....	.9275	.9285	.9295	.9305	.9315	.9325	.9335	.9345	.9355	.9365
54.....	.9279	.9289	.9299	.9309	.9319	.9329	.9339	.9349	.9359	.9369

TABLES

TABLE VI.—TEMPERATURE CORRECTIONS TO READINGS OF SPECIFIC GRAVITY HYDROMETERS IN AMERICAN PETROLEUM OILS AT VARIOUS TEMPERATURES.—*Continued*

Observed temperature in ° F.	Observed specific gravity								
	0.930	0.931	0.932	0.933	0.934	0.935	0.936	0.937	0.938
	Corresponding specific gravities at 60°/60° F.								
55.....	.9282	.9292	.9302	.9312	.9322	.9332	.9342	.9352	.9362
56.....	.9286	.9296	.9306	.9316	.9326	.9336	.9346	.9356	.9366
57.....	.9290	.9300	.9310	.9320	.9330	.9340	.9350	.9360	.9370
58.....	.9293	.9303	.9313	.9323	.9333	.9343	.9353	.9363	.9373
59.....	.9297	.9307	.9317	.9327	.9337	.9347	.9357	.9367	.9377
60.....	.9300	.9310	.9320	.9330	.9340	.9350	.9360	.9370	.9380
61.....	.9304	.9314	.9324	.9334	.9344	.9354	.9364	.9374	.9384
62.....	.9307	.9317	.9327	.9337	.9347	.9357	.9367	.9377	.9387
63.....	.9310	.9320	.9330	.9340	.9350	.9360	.9370	.9380	.9390
64.....	.9314	.9324	.9334	.9344	.9354	.9364	.9374	.9384	.9394
65.....	.9318	.9328	.9338	.9348	.9358	.9368	.9378	.9388	.9398
66.....	.9321	.9331	.9341	.9351	.9361	.9371	.9381	.9391	.9401
67.....	.9325	.9335	.9345	.9355	.9365	.9375	.9385	.9395	.9405
68.....	.9328	.9338	.9348	.9358	.9368	.9378	.9388	.9398	.9408
69.....	.9332	.9342	.9352	.9362	.9372	.9382	.9392	.9402	.9412
70.....	.9335	.9345	.9355	.9365	.9375	.9385	.9395	.9405	.9415
71.....	.9339	.9349	.9359	.9369	.9379	.9389	.9399	.9409	.9419
72.....	.9342	.9352	.9362	.9372	.9382	.9392	.9402	.9412	.9422
73.....	.9346	.9356	.9366	.9376	.9386	.9396	.9406	.9416	.9426
74.....	.9350	.9360	.9370	.9380	.9390	.9400	.9410	.9420	.9430
75.....	.9353	.9363	.9373	.9383	.9393	.9403	.9413	.9423	.9433
76.....	.9357	.9367	.9377	.9387	.9397	.9406	.9416	.9426	.9436
77.....	.9360	.9370	.9380	.9390	.9400	.9410	.9420	.9430	.9440
78.....	.9364	.9374	.9384	.9394	.9404	.9413	.9423	.9433	.9443
79.....	.9367	.9377	.9387	.9397	.9407	.9416	.9426	.9436	.9446
80.....	.9370	.9380	.9390	.9400	.9410	.9420	.9430	.9440	.9450
81.....	.9374	.9384	.9394	.9404	.9414	.9424	.9434	.9444	.9454
82.....	.9378	.9388	.9398	.9408	.9418	.9427	.9437	.9447	.9457
83.....	.9381	.9391	.9401	.9411	.9421	.9431	.9441	.9451	.9461
84.....	.9385	.9395	.9405	.9415	.9425	.9435	.9445	.9455	.9465
85.....	.9389	.9399	.9409	.9419	.9429	.9438	.9448	.9458	.9468
86.....	.9392	.9402	.9412	.9422	.9432	.9441	.9451	.9461	.9471
87.....	.9396	.9406	.9416	.9426	.9436	.9445	.9455	.9465	.9475
88.....	.9399	.9409	.9419	.9429	.9439	.9449	.9459	.9469	.9479
89.....	.9403	.9413	.9423	.9433	.9443	.9452	.9462	.9472	.9482
90.....	.9406	.9416	.9426	.9436	.9446	.9455	.9465	.9475	.9485
91.....	.9410	.9420	.9430	.9440	.9450	.9459	.9469	.9479	.9489
92.....	.9413	.9423	.9433	.9443	.9453	.9463	.9473	.9483	.9493
93.....	.9417	.9427	.9437	.9447	.9457	.9466	.9476	.9486	.9496
94.....	.9420	.9430	.9440	.9450	.9460	.9469	.9479	.9489	.9499
95.....	.9423	.9433	.9443	.9453	.9463	.9473	.9483	.9493	.9503
96.....	.9427	.9437	.9447	.9457	.9467	.9476	.9486	.9496	.9506
97.....	.9430	.9440	.9450	.9460	.9470	.9479	.9489	.9499	.9509
98.....	.9434	.9444	.9454	.9464	.9474	.9483	.9493	.9503	.9513
99.....	.9437	.9447	.9457	.9467	.9477	.9486	.9496	.9506	.9516
100.....	.9440	.9450	.9460	.9470	.9480	.9490	.9500	.9510	.9520
101.....	.9444	.9454	.9464	.9474	.9484	.9493	.9503	.9513	.9523
102.....	.9447	.9457	.9467	.9477	.9487	.9496	.9506	.9516	.9526
103.....	.9450	.9460	.9470	.9480	.9490	.9500	.9510	.9520	.9530
104.....	.9454	.9464	.9474	.9484	.9494	.9504	.9514	.9524	.9534
105.....	.9457	.9467	.9477	.9487	.9497	.9507	.9517	.9527	.9537
106.....	.9460	.9470	.9480	.9490	.9500	.9510	.9520	.9530	.9540
107.....	.9463	.9473	.9483	.9493	.9503	.9513	.9523	.9533	.9543
108.....	.9467	.9477	.9487	.9497	.9507	.9517	.9527	.9537	.9547
109.....	.9470	.9480	.9490	.9500	.9510	.9520	.9530	.9540	.9550
110.....	.9474	.9484	.9494	.9504	.9514	.9524	.9534	.9544	.9554
111.....	.9477	.9487	.9497	.9507	.9517	.9527	.9537	.9547	.9557
112.....	.9481	.9491	.9501	.9511	.9521	.9531	.9541	.9551	.9561
113.....	.9485	.9495	.9505	.9515	.9525	.9534	.9544	.9554	.9564
114.....	.9488	.9498	.9508	.9518	.9528	.9537	.9547	.9557	.9567
115.....	.9491	.9501	.9511	.9521	.9531	.9540	.9550	.9560	.9570
116.....	.9494	.9504	.9514	.9524	.9534	.9544	.9554	.9564	.9574
117.....	.9497	.9507	.9517	.9527	.9537	.9547	.9557	.9567	.9577
118.....	.9500	.9510	.9520	.9530	.9540	.9550	.9560	.9570	.9580
119.....	.9504	.9514	.9524	.9534	.9544	.9554	.9564	.9574	.9584

TABLES

TABLE VI.—TEMPERATURE CORRECTIONS TO READINGS OF SPECIFIC GRAVITY HYDROMETERS IN AMERICAN PETROLEUM OILS AT VARIOUS TEMPERATURES.—*Continued.*

Observed temperature in ° F.	Observed specific gravity									
	0.940	0.941	0.942	0.943	0.944	0.945	0.946	0.947	0.948	0.949
	Corresponding specific gravities at 60°/60° F.									
30.....	.9293	.9303	.9313	.9323	.9333	.9343	.9353	.9363	.9373	.9383
31.....	.9297	.9307	.9317	.9327	.9337	.9347	.9357	.9367	.9377	.9387
32.....	.9300	.9310	.9320	.9330	.9340	.9350	.9360	.9370	.9380	.9390
33.....	.9304	.9314	.9324	.9334	.9344	.9354	.9364	.9374	.9384	.9394
34.....	.9307	.9317	.9327	.9337	.9347	.9357	.9367	.9377	.9387	.9397
35.....	.9311	.9321	.9331	.9341	.9351	.9361	.9371	.9381	.9391	.9401
36.....	.9314	.9324	.9334	.9344	.9354	.9364	.9374	.9384	.9394	.9404
37.....	.9318	.9328	.9338	.9348	.9358	.9368	.9378	.9388	.9398	.9408
38.....	.9322	.9332	.9342	.9352	.9372	.9372	.9382	.9392	.9402	.9412
39.....	.9325	.9335	.9345	.9355	.9365	.9375	.9385	.9395	.9405	.9415
40.....	.9329	.9339	.9349	.9359	.9369	.9379	.9389	.9399	.9409	.9419
41.....	.9332	.9342	.9352	.9362	.9372	.9382	.9392	.9402	.9412	.9422
42.....	.9336	.9346	.9356	.9366	.9376	.9386	.9396	.9406	.9416	.9426
43.....	.9340	.9350	.9360	.9370	.9380	.9390	.9400	.9410	.9420	.9430
44.....	.9343	.9353	.9363	.9373	.9383	.9393	.9403	.9413	.9423	.9433
45.....	.9347	.9357	.9367	.9377	.9387	.9397	.9407	.9417	.9427	.9437
46.....	.9350	.9360	.9370	.9380	.9390	.9400	.9410	.9420	.9430	.9440
47.....	.9354	.9364	.9374	.9384	.9394	.9404	.9414	.9424	.9434	.9444
48.....	.9357	.9367	.9377	.9387	.9397	.9407	.9417	.9427	.9437	.9447
49.....	.9361	.9371	.9381	.9391	.9401	.9411	.9421	.9431	.9441	.9451
50.....	.9365	.9375	.9385	.9395	.9405	.9415	.9425	.9435	.9445	.9455
51.....	.9368	.9378	.9388	.9398	.9408	.9418	.9428	.9438	.9448	.9458
52.....	.9372	.9382	.9392	.9402	.9412	.9422	.9432	.9442	.9452	.9462
53.....	.9375	.9385	.9395	.9405	.9415	.9425	.9435	.9445	.9455	.9465
54.....	.9379	.9389	.9399	.9409	.9419	.9429	.9439	.9449	.9459	.9469
55.....	.9382	.9392	.9402	.9412	.9422	.9432	.9442	.9452	.9462	.9472
56.....	.9386	.9396	.9406	.9416	.9426	.9436	.9446	.9456	.9466	.9476
57.....	.9390	.9400	.9410	.9420	.9430	.9440	.9450	.9460	.9470	.9480
58.....	.9393	.9403	.9413	.9423	.9433	.9443	.9453	.9463	.9473	.9483
59.....	.9397	.9407	.9417	.9427	.9437	.9447	.9457	.9467	.9477	.9487
60.....	.9400	.9410	.9420	.9430	.9440	.9450	.9460	.9470	.9480	.9490
61.....	.9404	.9414	.9424	.9434	.9444	.9454	.9464	.9474	.9484	.9494
62.....	.9407	.9417	.9427	.9437	.9447	.9457	.9467	.9477	.9487	.9497
63.....	.9410	.9420	.9430	.9440	.9450	.9460	.9470	.9480	.9490	.9500
64.....	.9414	.9424	.9434	.9444	.9454	.9464	.9474	.9484	.9494	.9504
65.....	.9418	.9428	.9438	.9448	.9458	.9468	.9478	.9488	.9498	.9508
66.....	.9421	.9431	.9441	.9451	.9461	.9471	.9481	.9491	.9501	.9511
67.....	.9425	.9435	.9445	.9455	.9465	.9475	.9485	.9495	.9505	.9515
68.....	.9428	.9438	.9448	.9458	.9468	.9478	.9488	.9498	.9508	.9518
69.....	.9432	.9442	.9452	.9462	.9472	.9481	.9491	.9501	.9511	.9521
70.....	.9435	.9445	.9455	.9465	.9475	.9485	.9495	.9505	.9515	.9525
71.....	.9439	.9449	.9459	.9469	.9479	.9488	.9498	.9508	.9518	.9528
72.....	.9442	.9452	.9462	.9472	.9482	.9492	.9502	.9512	.9522	.9532
73.....	.9446	.9456	.9466	.9476	.9486	.9495	.9505	.9515	.9525	.9535
74.....	.9450	.9460	.9470	.9480	.9490	.9499	.9509	.9519	.9529	.9539
75.....	.9453	.9463	.9473	.9483	.9493	.9503	.9513	.9523	.9533	.9543
76.....	.9456	.9466	.9476	.9486	.9496	.9506	.9516	.9526	.9536	.9546
77.....	.9460	.9470	.9480	.9490	.9500	.9510	.9520	.9530	.9540	.9550
78.....	.9463	.9473	.9483	.9493	.9503	.9513	.9523	.9533	.9543	.9553
79.....	.9466	.9476	.9486	.9496	.9506	.9516	.9526	.9536	.9546	.9556
80.....	.9470	.9480	.9490	.9500	.9510	.9520	.9530	.9540	.9550	.9560
81.....	.9474	.9484	.9494	.9504	.9514	.9524	.9534	.9544	.9554	.9564
82.....	.9477	.9487	.9497	.9507	.9517	.9527	.9537	.9547	.9557	.9567
83.....	.9481	.9491	.9501	.9511	.9521	.9531	.9541	.9551	.9561	.9571
84.....	.9485	.9495	.9505	.9515	.9525	.9534	.9544	.9554	.9564	.9574
85.....	.9488	.9498	.9508	.9518	.9528	.9538	.9548	.9558	.9568	.9578
86.....	.9491	.9501	.9511	.9521	.9531	.9541	.9551	.9561	.9571	.9581
87.....	.9495	.9505	.9515	.9525	.9535	.9545	.9555	.9565	.9575	.9585
88.....	.9499	.9509	.9519	.9529	.9539	.9548	.9558	.9568	.9578	.9588
89.....	.9502	.9512	.9522	.9532	.9542	.9552	.9562	.9572	.9582	.9592

TABLES

TABLE VI.—TEMPERATURE CORRECTIONS TO READINGS OF SPECIFIC GRAVITY HYDROMETERS IN AMERICAN PETROLEUM OILS AT VARIOUS TEMPERATURES.—*Continued.*

Observed temperature in ° F.	Observed specific gravity									
	0.940	0.941	0.942	0.943	0.944	0.945	0.946	0.947	0.948	0.949
	Corresponding specific gravities at 60°/60° F.									
90.....	.9505	.9515	.9525	.9535	.9545	.9555	.9565	.9575	.9585	.9595
91.....	.9509	.9519	.9529	.9539	.9549	.9559	.9569	.9579	.9589	.9599
92.....	.9513	.9523	.9533	.9543	.9553	.9562	.9572	.9582	.9592	.9602
93.....	.9516	.9526	.9536	.9546	.9556	.9565	.9575	.9585	.9595	.9605
94.....	.9519	.9529	.9539	.9549	.9559	.9568	.9578	.9588	.9598	.9608
95.....	.9523	.9533	.9543	.9553	.9563	.9572	.9582	.9592	.9602	.9612
96.....	.9526	.9536	.9546	.9556	.9566	.9575	.9585	.9595	.9605	.9615
97.....	.9529	.9539	.9549	.9559	.9569	.9579	.9589	.9599	.9609	.9619
98.....	.9533	.9543	.9553	.9563	.9573	.9583	.9593	.9603	.9613	.9623
99.....	.9536	.9546	.9556	.9566	.9576	.9586	.9596	.9606	.9616	.9626
100.....	.9540	.9550	.9560	.9570	.9580	.9589	.9599	.9609	.9619	.9629
101.....	.9543	.9553	.9563	.9573	.9583	.9593	.9603	.9613	.9623	.9633
102.....	.9546	.9556	.9566	.9576	.9586	.9596	.9606	.9616	.9626	.9636
103.....	.9550	.9560	.9570	.9580	.9590	.9599	.9609	.9619	.9629	.9639
104.....	.9554	.9564	.9574	.9584	.9594	.9603	.9613	.9623	.9633	.9643
105.....	.9557	.9567	.9577	.9587	.9597	.9606	.9616	.9626	.9636	.9646
106.....	.9560	.9570	.9580	.9590	.9600	.9609	.9619	.9629	.9639	.9649
107.....	.9563	.9573	.9583	.9593	.9603	.9613	.9623	.9633	.9643	.9653
108.....	.9567	.9577	.9587	.9597	.9607	.9616	.9626	.9636	.9646	.9656
109.....	.9570	.9580	.9590	.9600	.9610	.9620	.9630	.9640	.9650	.9660
110.....	.9574	.9584	.9594	.9604	.9614	.9623	.9633	.9643	.9653	.9663
111.....	.9577	.9587	.9597	.9607	.9617	.9626	.9636	.9646	.9656	.9666
112.....	.9581	.9591	.9601	.9611	.9621	.9630	.9640	.9650	.9660	.9670
113.....	.9584	.9594	.9604	.9614	.9624	.9634	.9644	.9654	.9664	.9674
114.....	.9587	.9597	.9607	.9617	.9627	.9637	.9647	.9657	.9667	.9677
115.....	.9590	.9600	.9610	.9620	.9630	.9640	.9650	.9660	.9670	.9680
116.....	.9594	.9604	.9614	.9624	.9634	.9644	.9654	.9664	.9674	.9684
117.....	.9597	.9607	.9617	.9627	.9637	.9647	.9657	.9667	.9677	.9687
118.....	.9600	.9610	.9620	.9630	.9640	.9650	.9660	.9670	.9680	.9690
119.....	.9604	.9614	.9624	.9634	.9644	.9654	.9664	.9674	.9684	.9694

TABLES

TABLE VII.—REDUCTION OF OBSERVED DEGREES A. P. I. TO DEGREES A. P. I. AT 60° F.

Observed temperature in °F.	Observed degrees A. P. I.									
	10	11	12	13	14	15	16	17	18	19
	Corresponding degrees A. P. I. at 60° F.									
30.....	11.5	12.5	13.6	14.6	15.6	16.6	17.7	18.7	19.7	20.7
31.....	11.5	12.5	13.5	14.5	15.6	16.6	17.6	18.6	19.7	20.7
32.....	11.4	12.4	13.4	14.5	15.5	16.5	17.6	18.6	19.6	20.6
33.....	11.4	12.4	13.4	14.4	15.5	16.5	17.5	18.5	19.5	20.6
34.....	11.3	12.3	13.3	14.4	15.4	16.4	17.4	18.4	19.5	20.5
35.....	11.3	12.3	13.3	14.3	15.3	16.4	17.4	18.4	19.4	20.4
36.....	11.2	12.2	13.2	14.3	15.3	16.3	17.3	18.3	19.4	20.4
37.....	11.2	12.2	13.2	14.2	15.2	16.3	17.3	18.3	19.3	20.3
38.....	11.1	12.1	13.1	14.2	15.2	16.2	17.2	18.2	19.2	20.3
39.....	11.1	12.1	13.1	14.1	15.1	16.1	17.2	18.2	19.2	20.2
40.....	11.0	12.0	13.0	14.0	15.1	16.1	17.1	18.1	19.1	20.1
41.....	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.1	19.1	20.1
42.....	10.9	11.9	12.9	13.9	15.0	16.0	17.0	18.0	19.0	20.0
43.....	10.8	11.9	12.9	13.9	14.9	15.9	16.9	17.9	18.9	20.0
44.....	10.8	11.8	12.8	13.8	14.9	15.9	16.9	17.9	18.9	19.9
45.....	10.7	11.8	12.8	13.8	14.8	15.8	16.8	17.8	18.8	19.9
46.....	10.7	11.7	12.7	13.7	14.8	15.8	16.8	17.8	18.8	19.8
47.....	10.6	11.7	12.7	13.7	14.7	15.7	16.7	17.7	18.7	19.7
48.....	10.6	11.6	12.6	13.6	14.6	15.6	16.7	17.7	18.7	19.7
49.....	10.6	11.6	12.6	13.6	14.6	15.6	16.6	17.6	18.6	19.6
50.....	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.6
51.....	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5
52.....	10.4	11.4	12.4	13.4	14.4	15.4	16.4	17.4	18.4	19.4
53.....	10.4	11.4	12.4	13.4	14.4	15.4	16.4	17.4	18.4	19.4
54.....	10.3	11.3	12.3	13.3	14.3	15.3	16.3	17.3	18.3	19.3
55.....	10.3	11.3	12.3	13.3	14.3	15.3	16.3	17.3	18.3	19.3
56.....	10.2	11.2	12.2	13.2	14.2	15.2	16.2	17.2	18.2	19.2
57.....	10.1	11.1	12.1	13.1	14.1	15.1	16.2	17.2	18.2	19.2
58.....	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1
59.....	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0
60.....	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0
61.....	9.9	10.9	11.9	12.9	13.9	14.9	15.9	16.9	17.9	18.9
62.....	9.9	10.9	11.9	12.9	13.9	14.9	15.9	16.9	17.9	18.9
63.....	9.9	10.8	11.8	12.8	13.8	14.8	15.8	16.8	17.8	18.8
64.....	9.8	10.8	11.8	12.8	13.8	14.8	15.8	16.8	17.8	18.8
65.....	9.8	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.7	18.7
66.....	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.7	18.7
67.....	9.7	10.6	11.6	12.6	13.6	14.6	15.6	16.6	17.6	18.6
68.....	9.6	10.6	11.6	12.6	13.6	14.6	15.6	16.6	17.6	18.5
69.....	9.6	10.6	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
70.....	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.4	17.4	18.4
71.....	9.5	10.5	11.4	12.5	13.4	14.4	15.4	16.4	17.4	18.4
72.....	9.4	10.4	11.4	12.4	13.4	14.4	15.4	16.3	17.3	18.3
73.....	9.4	10.4	11.3	12.3	13.3	14.3	15.3	16.3	17.3	18.3
74.....	9.3	10.3	11.3	12.3	13.3	14.3	15.2	16.2	17.2	18.2
75.....	9.3	10.2	11.2	12.2	13.2	14.2	15.2	16.2	17.2	18.2
76.....	9.2	10.2	11.2	12.2	13.2	14.2	15.1	16.1	17.1	18.1
77.....	9.2	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.0
78.....	9.1	10.1	11.1	12.1	13.1	14.0	15.0	16.0	17.0	18.0
79.....	9.1	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	17.9
80.....	9.0	10.0	11.0	12.0	13.0	13.9	14.9	15.9	16.9	17.9
81.....	9.0	9.9	10.9	11.9	12.9	13.9	14.9	15.8	16.8	17.8
82.....	8.9	9.9	10.9	11.9	12.9	13.8	14.8	15.8	16.8	17.8
83.....	8.9	9.8	10.8	11.8	12.8	13.8	14.8	15.7	16.7	17.7
84.....	8.8	9.8	10.8	11.8	12.8	13.7	14.7	15.7	16.7	17.7
85.....	8.8	9.8	10.7	11.7	12.7	13.7	14.7	15.6	16.6	17.6
86.....	8.7	9.7	10.7	11.7	12.6	13.6	14.6	15.6	16.6	17.6
87.....	8.7	9.7	10.6	11.6	12.6	13.6	14.6	15.5	16.5	17.5
88.....	8.6	9.6	10.6	11.6	12.5	13.5	14.5	15.5	16.5	17.4
89.....	8.6	9.6	10.5	11.5	12.5	13.5	14.5	15.4	16.4	17.4
90.....	8.5	9.5	10.5	11.5	12.4	13.4	14.4	15.4	16.4	17.3
91.....	8.5	9.5	10.4	11.4	12.4	13.4	14.4	15.3	16.3	17.3
92.....	8.4	9.4	10.4	11.4	12.3	13.3	14.3	15.3	16.3	17.2
93.....	8.4	9.4	10.3	11.3	12.3	13.3	14.3	15.2	16.2	17.2
94.....	8.3	9.3	10.3	11.3	12.2	13.2	14.2	15.2	16.2	17.1

TABLES

TABLE VII. REDUCTION OF OBSERVED DEGREES A. P. I. TO DEGREES A. P. I. AT 60° F.

Continued.

Observed temperature in ° F.	Observed degrees A. P. I.									
	10	11	12	13	14	15	16	17	18	19
	Corresponding degrees A. P. I. at 60° F.									
95.....	8.3	9.3	10.2	11.2	12.2	13.2	14.2	15.1	16.1	17.1
96.....	8.2	9.2	10.2	11.2	12.1	13.1	14.1	15.1	16.0	17.0
97.....	8.2	9.2	10.1	11.1	12.1	13.1	14.0	15.0	16.0	17.0
98.....	8.1	9.1	10.1	11.1	12.0	13.0	14.0	15.0	15.9	16.9
99.....	8.1	9.1	10.0	11.0	12.0	13.0	13.9	14.9	15.9	16.8
100.....	8.1	9.0	10.0	11.0	11.9	12.9	13.9	14.9	15.8	16.8
101.....	8.0	9.0	9.9	10.9	11.9	12.9	13.8	14.8	15.8	16.7
102.....	8.0	8.9	9.9	10.9	11.8	12.8	13.8	14.8	15.7	16.7
103.....	7.9	8.9	9.9	10.8	11.8	12.8	13.7	14.7	15.7	16.6
104.....	7.9	8.8	9.8	10.8	11.7	12.7	13.7	14.7	15.6	16.6
105.....	7.8	8.8	9.8	10.7	11.7	12.7	13.6	14.6	15.6	16.5
106.....	7.8	8.8	9.7	10.7	11.7	12.6	13.6	14.6	15.5	16.5
107.....	7.7	8.7	9.7	10.6	11.6	12.6	13.5	14.5	15.5	16.4
108.....	7.7	8.7	9.6	10.6	11.6	12.5	13.5	14.5	15.4	16.4
109.....	7.6	8.6	9.6	10.5	11.5	12.5	13.4	14.4	15.4	16.3
110.....	7.6	8.6	9.5	10.5	11.5	12.4	13.4	14.4	15.3	16.3
111.....	7.6	8.5	9.5	10.4	11.4	12.4	13.3	14.3	15.3	16.2
112.....	7.5	8.5	9.4	10.4	11.4	12.3	13.3	14.2	15.2	16.2
113.....	7.5	8.4	9.4	10.3	11.3	12.3	13.2	14.2	15.1	16.1
114.....	7.4	8.4	9.3	10.3	11.3	12.2	13.2	14.1	15.1	16.1
115.....	7.4	8.3	9.3	10.2	11.2	12.2	13.1	14.1	15.0	16.0
116.....	7.3	8.3	9.2	10.2	11.2	12.1	13.1	14.0	15.0	16.0
117.....	7.3	8.2	9.2	10.1	11.1	12.1	13.0	14.0	14.9	15.9
118.....	7.2	8.2	9.1	10.1	11.1	12.0	13.0	13.9	14.9	15.9
119.....	7.2	8.1	9.1	10.1	11.0	12.0	12.9	13.9	14.8	15.8

Observed temperature in ° F.	Observed degrees A. P. I.									
	20	21	22	23	24	25	26	27	28	29
	Corresponding degrees A. P. I. at 60° F.									
30.....	21.7	22.8	23.8	24.8	25.8	26.9	27.9	28.9	30.0	31.0
31.....	21.7	22.7	23.7	24.7	25.8	26.8	27.8	28.9	29.9	30.9
32.....	21.6	22.7	23.7	24.7	25.7	26.8	27.8	28.8	29.8	30.9
33.....	21.6	22.6	23.6	24.6	25.7	26.7	27.7	28.7	29.8	30.8
34.....	21.5	22.5	23.6	24.6	25.6	26.6	27.7	28.7	29.7	30.7
35.....	21.4	22.5	23.5	24.5	25.5	26.6	27.6	28.6	29.6	30.7
36.....	21.4	22.4	23.4	24.4	25.5	26.5	27.5	28.5	29.6	30.6
37.....	21.3	22.3	23.4	24.4	25.4	26.4	27.4	28.5	29.5	30.5
38.....	21.3	22.3	23.3	24.3	25.3	26.3	27.4	28.4	29.4	30.4
39.....	21.2	22.2	23.3	24.3	25.3	26.3	27.3	28.3	29.4	30.4
40.....	21.2	22.2	23.2	24.2	25.2	26.2	27.3	28.3	29.3	30.3
41.....	21.1	22.1	23.1	24.2	25.2	26.2	27.2	28.2	29.2	30.3
42.....	21.0	22.1	23.1	24.1	25.1	26.1	27.1	28.2	29.2	30.2
43.....	21.0	22.0	23.0	24.0	25.0	26.0	27.1	28.1	29.1	30.1
44.....	20.9	21.9	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0
45.....	20.9	21.9	22.9	23.9	24.9	25.9	26.9	28.0	29.0	30.0
46.....	20.8	21.8	22.8	23.8	24.8	25.9	26.9	27.9	28.9	29.9
47.....	20.7	21.7	22.8	23.8	24.8	25.8	26.8	27.8	28.8	29.8
48.....	20.7	21.7	22.7	23.7	24.7	25.7	26.8	27.8	28.8	29.8
49.....	20.6	21.6	22.7	23.7	24.7	25.7	26.7	27.7	28.7	29.7
50.....	20.6	21.6	22.6	23.6	24.6	25.6	26.6	27.6	28.7	29.7
51.....	20.5	21.5	22.5	23.5	24.5	25.5	26.6	27.6	28.6	29.6
52.....	20.5	21.5	22.5	23.5	24.5	25.5	26.5	27.5	28.5	29.5
53.....	20.4	21.4	22.4	23.4	24.4	25.4	26.4	27.4	28.5	29.5
54.....	20.3	21.3	22.3	23.3	24.4	25.4	26.4	27.4	28.4	29.4
55.....	20.3	21.3	22.3	23.3	24.3	25.3	26.3	27.3	28.3	29.3
56.....	20.2	21.2	22.2	23.2	24.2	25.2	26.2	27.3	28.3	29.3
57.....	20.2	21.2	22.2	23.2	24.2	25.2	26.2	27.2	28.2	29.2
58.....	20.1	21.1	22.1	23.1	24.1	25.1	26.1	27.1	28.1	29.1
59.....	20.1	21.1	22.1	23.1	24.1	25.1	26.1	27.1	28.1	29.1

TABLES

TABLE VII.—REDUCTION OF OBSERVED DEGREES A. P. I. TO DEGREES A. P. I. AT 60° F.—
Continued.

Observed temperature in ° F.	Observed degrees A. P. I.									
	20	21	22	23	24	25	26	27	28	29
	Corresponding degrees A. P. I. at 60° F.									
60.....	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0
61.....	19.9	20.9	21.9	22.9	23.9	24.9	25.9	26.9	27.9	28.9
62.....	19.9	20.9	21.9	22.9	23.9	24.9	25.9	26.9	27.9	28.9
63.....	19.8	20.8	21.8	22.8	23.8	24.8	25.8	26.8	27.8	28.8
64.....	19.8	20.8	21.8	22.8	23.8	24.8	25.8	26.8	27.8	28.8
65.....	19.7	20.7	21.7	22.7	23.7	24.7	25.7	26.7	27.7	28.7
66.....	19.7	20.7	21.7	22.6	23.6	24.6	25.6	26.6	27.6	28.6
67.....	19.6	20.6	21.6	22.6	23.6	24.6	25.6	26.6	27.6	28.5
68.....	19.5	20.5	21.5	22.5	23.5	24.5	25.5	26.5	27.5	28.5
69.....	19.5	20.5	21.5	22.4	23.4	24.4	25.4	26.4	27.4	28.4
70.....	19.4	20.4	21.4	22.4	23.4	24.4	25.4	26.4	27.4	28.3
71.....	19.4	20.4	21.4	22.3	23.3	24.3	25.3	26.3	27.3	28.3
72.....	19.3	20.3	21.3	22.3	23.3	24.3	25.2	26.2	27.2	28.2
73.....	19.2	20.2	21.2	22.2	23.2	24.2	25.2	26.2	27.2	28.2
74.....	19.2	20.2	21.2	22.2	23.1	24.1	25.1	26.1	27.1	28.1
75.....	19.1	20.1	21.1	22.1	23.1	24.1	25.1	26.0	27.0	28.0
76.....	19.1	20.1	21.1	22.0	23.0	24.0	25.0	26.0	27.0	28.0
77.....	19.0	20.0	21.0	22.0	23.0	24.0	25.0	25.9	26.9	27.9
78.....	19.0	20.0	20.9	21.9	22.9	23.9	24.9	25.9	26.8	27.8
79.....	18.9	19.9	20.9	21.8	22.8	23.8	24.8	25.8	26.8	27.8
80.....	18.9	19.9	20.8	21.8	22.8	23.8	24.8	25.7	26.7	27.7
81.....	18.8	19.8	20.8	21.7	22.7	23.7	24.7	25.7	26.7	27.6
82.....	18.7	19.7	20.7	21.7	22.7	23.6	24.6	25.6	26.6	27.6
83.....	18.7	19.7	20.6	21.6	22.6	23.6	24.6	25.5	26.5	27.5
84.....	18.6	19.6	20.6	21.6	22.6	23.5	24.5	25.5	26.5	27.4
85.....	18.6	19.5	20.5	21.5	22.5	23.5	24.5	25.4	26.4	27.4
86.....	18.5	19.5	20.5	21.4	22.4	23.4	24.4	25.4	26.3	27.3
87.....	18.4	19.4	20.4	21.4	22.4	23.3	24.3	25.3	26.3	27.3
88.....	18.4	19.4	20.4	21.3	22.3	23.3	24.3	25.2	26.2	27.2
89.....	18.3	19.3	20.3	21.3	22.2	23.2	24.2	25.2	26.2	27.1
90.....	18.3	19.3	20.3	21.2	22.2	23.2	24.2	25.1	26.1	27.1
91.....	18.2	19.2	20.2	21.2	22.1	23.1	24.1	25.1	26.0	27.0
92.....	18.2	19.2	20.1	21.1	22.1	23.0	24.0	25.0	26.0	26.9
93.....	18.1	19.1	20.1	21.0	22.0	23.0	24.0	24.9	25.9	26.9
94.....	18.1	19.0	20.0	21.0	22.0	22.9	23.9	24.9	25.9	26.8
95.....	18.0	19.0	20.0	20.9	21.9	22.9	23.8	24.8	25.8	26.8
96.....	18.0	18.9	19.9	20.9	21.9	22.8	23.8	24.8	25.8	26.7
97.....	17.9	18.9	19.9	20.8	21.8	22.8	23.7	24.7	25.7	26.6
98.....	17.9	18.8	19.8	20.8	21.7	22.7	23.7	24.6	25.6	26.6
99.....	17.8	18.8	19.8	20.7	21.7	22.7	23.6	24.6	25.6	26.5
100.....	17.8	18.7	19.7	20.7	21.6	22.6	23.6	24.5	25.5	26.5
101.....	17.7	18.7	19.6	20.6	21.6	22.5	23.5	24.5	25.4	26.4
102.....	17.6	18.6	19.6	20.5	21.5	22.5	23.4	24.4	25.4	26.3
103.....	17.6	18.6	19.5	20.5	21.5	22.4	23.4	24.4	25.3	26.3
104.....	17.5	18.5	19.5	20.4	21.4	22.3	23.3	24.3	25.2	26.2
105.....	17.5	18.5	19.4	20.4	21.3	22.3	23.3	24.2	25.2	26.1
106.....	17.4	18.4	19.4	20.3	21.3	22.2	23.2	24.2	25.1	26.1
107.....	17.4	18.4	19.3	20.3	21.2	22.2	23.2	24.1	25.1	26.0
108.....	17.3	18.3	19.3	20.2	21.2	22.1	23.1	24.0	25.0	25.9
109.....	17.3	18.3	19.2	20.2	21.1	22.1	23.0	24.0	24.9	25.9
110.....	17.2	18.2	19.2	20.1	21.1	22.0	23.0	23.9	24.9	25.8
111.....	17.2	18.1	19.1	20.1	21.0	22.0	22.9	23.9	24.8	25.8
112.....	17.1	18.1	19.0	20.0	20.9	21.9	22.9	23.8	24.8	25.7
113.....	17.1	18.0	19.0	19.9	20.9	21.8	22.8	23.7	24.7	25.6
114.....	17.0	18.0	18.9	19.9	20.8	21.8	22.8	23.7	24.7	25.6
115.....	17.0	17.9	18.9	19.8	20.8	21.7	22.7	23.6	24.6	25.5
116.....	16.9	17.9	18.8	19.8	20.7	21.7	22.6	23.6	24.5	25.5
117.....	16.9	17.8	18.8	19.7	20.7	21.6	22.6	23.5	24.5	25.4
118.....	16.8	17.8	18.7	19.7	20.6	21.6	22.5	23.5	24.4	25.3
119.....	16.8	17.7	18.7	19.6	20.6	21.5	22.5	23.4	24.4	25.3

TABLES

TABLE VIII DEGREES A. P. I., POUNDS PER GALLON, AND GALLONS PER POUND, CORRESPONDING TO THE DESIGNATED SPECIFIC GRAVITY.

Specific gravity at 60°/60° F.	Degrees A. P. I.	Pounds per gallon	Gallons per pound	Specific gravity at 60°/60° F.	Degrees A. P. I.	Pounds per gallon	Gallons per pound
0.880	29.30	7.328	0.1365	0.915	23.14	7.620	0.1312
.881	29.11	7.336	.1363	.916	22.98	7.628	.1311
.882	28.93	7.344	.1362	.917	22.81	7.636	.1310
.883	28.75	7.353	.1360	.918	22.64	7.645	.1308
.884	28.57	7.361	.1358	.919	22.47	7.653	.1307
.885	28.39	7.369	.1357	.920	22.30	7.661	.1305
.886	28.21	7.378	.1355	.921	22.14	7.670	.1304
.887	28.03	7.386	.1354	.922	21.97	7.678	.1302
.888	27.85	7.394	.1352	.923	21.80	7.686	.1301
.889	27.67	7.403	.1351	.924	21.64	7.695	.1300
.890	27.49	7.411	.1349	.925	21.47	7.703	.1298
.891	27.31	7.419	.1348	.926	21.31	7.711	.1297
.892	27.13	7.428	.1346	.927	21.14	7.720	.1295
.893	26.95	7.436	.1345	.928	20.98	7.728	.1294
.894	26.78	7.444	.1343	.929	20.81	7.736	.1293
.895	26.60	7.453	.1342	.930	20.65	7.745	.1291
.896	26.42	7.461	.1340	.931	20.49	7.753	.1290
.897	26.25	7.469	.1339	.932	20.32	7.761	.1288
.898	26.07	7.478	.1337	.933	20.16	7.770	.1287
.899	25.90	7.486	.1336	.934	20.00	7.778	.1286
.900	25.72	7.494	.1334	.935	19.84	7.786	.1284
.901	25.55	7.503	.1333	.936	19.68	7.795	.1283
.902	25.37	7.511	.1331	.937	19.51	7.803	.1282
.903	25.20	7.519	.1330	.938	19.35	7.811	.1280
.904	25.03	7.528	.1328	.939	19.19	7.820	.1279
.905	24.85	7.536	.1327	.940	19.03	7.828	.1278
.906	24.68	7.544	.1326	.941	18.87	7.836	.1276
.907	24.51	7.553	.1324	.942	18.71	7.845	.1275
.908	24.34	7.561	.1323	.943	18.55	7.853	.1273
.909	24.17	7.569	.1321	.944	18.39	7.861	.1272
.910	23.99	7.578	.1320	.945	18.24	7.870	.1271
.911	23.82	7.586	.1318	.946	18.08	7.878	.1269
.912	23.65	7.594	.1317	.947	17.92	7.886	.1268
.913	23.48	7.603	.1315	.948	17.76	7.895	.1267
.914	23.31	7.611	.1314	.949	17.60	7.903	.1265

TABLES

TABLE IX.—SPECIFIC GRAVITIES, POUNDS PER GALLON, AND GALLONS PER POUND, CORRESPONDING TO THE DESIGNATED DEGREES A. P. I.

Degrees A. P. I.	Specific gravity at 60°/60° F.	Pounds per gallon	Gallons per pound	Degrees A. P. I.	Specific gravity at 60°/60° F.	Pounds per gallon	Gallons per pound
17.0	0.9529	7.935	0.1260	23.5	0.9129	7.602	0.1311
17.1	.9522	7.930	.1261	23.6	.9123	7.597	.1316
17.2	.9516	7.925	.1262	23.7	.9117	7.592	.1317
17.3	.9509	7.919	.1263	23.8	.9111	7.587	.1318
17.4	.9503	7.914	.1264	23.9	.9106	7.583	.1319
17.5	.9497	7.909	.1264	24.0	.9100	7.578	.1320
17.6	.9490	7.903	.1265	24.1	.9094	7.573	.1320
17.7	.9484	7.898	.1266	24.2	.9088	7.568	.1321
17.8	.9478	7.893	.1267	24.3	.9082	7.563	.1322
17.9	.9471	7.887	.1268	24.4	.9076	7.558	.1323
18.0	.9465	7.882	.1269	24.5	.9071	7.554	.1324
18.1	.9459	7.877	.1270	24.6	.9065	7.549	.1325
18.2	.9452	7.871	.1270	24.7	.9059	7.544	.1326
18.3	.9446	7.866	.1271	24.8	.9053	7.539	.1326
18.4	.9440	7.861	.1272	24.9	.9047	7.534	.1327
18.5	.9433	7.856	.1273	25.0	.9042	7.529	.1328
18.6	.9427	7.851	.1274	25.1	.9036	7.524	.1329
18.7	.9421	7.846	.1275	25.2	.9030	7.519	.1330
18.8	.9415	7.841	.1275	25.3	.9024	7.514	.1331
18.9	.9408	7.835	.1276	25.4	.9018	7.509	.1332
19.0	.9402	7.830	.1277	25.5	.9013	7.505	.1332
19.1	.9396	7.825	.1278	25.6	.9007	7.500	.1333
19.2	.9390	7.820	.1279	25.7	.9001	7.495	.1334
19.3	.9383	7.814	.1280	25.8	.8996	7.491	.1335
19.4	.9377	7.809	.1281	25.9	.8990	7.486	.1336
19.5	.9371	7.804	.1281	26.0	.8984	7.481	.1337
19.6	.9365	7.799	.1282	26.1	.8978	7.476	.1338
19.7	.9358	7.793	.1283	26.2	.8973	7.472	.1338
19.8	.9352	7.788	.1284	26.3	.8967	7.467	.1339
19.9	.9346	7.783	.1285	26.4	.8961	7.462	.1340
20.0	.9340	7.778	.1286	26.5	.8956	7.458	.1341
20.1	.9334	7.773	.1287	26.6	.8950	7.453	.1342
20.2	.9328	7.768	.1287	26.7	.8944	7.448	.1343
20.3	.9321	7.762	.1288	26.8	.8939	7.443	.1344
20.4	.9315	7.757	.1289	26.9	.8933	7.438	.1344
20.5	.9309	7.752	.1290	27.0	.8927	7.434	.1345
20.6	.9303	7.747	.1291	27.1	.8922	7.429	.1346
20.7	.9297	7.742	.1292	27.2	.8916	7.424	.1347
20.8	.9291	7.737	.1292	27.3	.8911	7.420	.1348
20.9	.9285	7.732	.1293	27.4	.8905	7.415	.1349
21.0	.9279	7.727	.1294	27.5	.8899	7.410	.1350
21.1	.9273	7.722	.1295	27.6	.8894	7.406	.1350
21.2	.9267	7.717	.1296	27.7	.8888	7.401	.1351
21.3	.9260	7.711	.1297	27.8	.8883	7.397	.1352
21.4	.9254	7.706	.1298	27.9	.8877	7.392	.1353
21.5	.9248	7.701	.1299	28.0	.8871	7.387	.1354
21.6	.9242	7.696	.1299	28.1	.8866	7.383	.1354
21.7	.9236	7.691	.1300	28.2	.8860	7.378	.1355
21.8	.9230	7.686	.1301	28.3	.8855	7.373	.1356
21.9	.9224	7.681	.1302	28.4	.8849	7.368	.1357
22.0	.9218	7.676	.1303	28.5	.8844	7.364	.1358
22.1	.9212	7.671	.1304	28.6	.8838	7.360	.1359
22.2	.9206	7.666	.1304	28.7	.8833	7.355	.1360
22.3	.9200	7.661	.1305	28.8	.8827	7.351	.1360
22.4	.9194	7.656	.1306	28.9	.8822	7.346	.1361
22.5	.9188	7.651	.1307	29.0	.8816	7.341	.1362
22.6	.9182	7.646	.1308	29.1	.8811	7.337	.1363
22.7	.9176	7.641	.1309	29.2	.8805	7.332	.1364
22.8	.9170	7.636	.1310	29.3	.8800	7.328	.1365
22.9	.9165	7.632	.1310	29.4	.8794	7.323	.1366
23.0	.9159	7.627	.1311	29.5	.8789	7.318	.1366
23.1	.9153	7.622	.1312	29.6	.8783	7.314	.1367
23.2	.9147	7.617	.1313	29.7	.8778	7.309	.1368
23.3	.9141	7.612	.1314	29.8	.8772	7.305	.1369
23.4	.9135	7.607	.1315	29.9	.8767	7.300	.1370

TABLES

TABLE X.—DEGREES A. P. I. (MODULUS 141.5) CORRESPONDING TO DEGREES BAUMÉ (MODULUS 140).

Degrees Baumé (modulus 140)	Tenths of degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
10.....	10.00	10.10	10.20	10.30	10.40	10.51	10.61	10.71	10.81	10.91
11.....	11.01	11.11	11.21	11.31	11.42	11.52	11.62	11.72	11.82	11.92
12.....	12.02	12.12	12.22	12.32	12.43	12.53	12.63	12.73	12.83	12.93
13.....	13.03	13.13	13.23	13.34	13.44	13.54	13.64	13.74	13.84	13.94
14.....	14.04	14.14	14.24	14.35	14.45	14.55	14.65	14.75	14.85	14.95
15.....	15.05	15.15	15.26	15.36	15.46	15.56	15.66	15.76	15.86	15.96
16.....	16.06	16.17	16.27	16.37	16.47	16.57	16.67	16.77	16.87	16.97
17.....	17.08	17.18	17.28	17.38	17.48	17.58	17.68	17.78	17.88	17.98
18.....	18.09	18.19	18.29	18.39	18.49	18.59	18.69	18.79	18.89	19.00
19.....	19.10	19.20	19.30	19.40	19.50	19.60	19.70	19.80	19.90	20.01
20.....	20.11	20.21	20.31	20.41	20.51	20.61	20.71	20.81	20.92	21.02
21.....	21.12	21.22	21.32	21.42	21.52	21.62	21.72	21.83	21.93	22.03
22.....	22.13	22.23	22.33	22.43	22.53	22.63	22.74	22.84	22.94	23.04
23.....	23.14	23.24	23.34	23.44	23.54	23.64	23.75	23.85	23.95	24.05
24.....	24.15	24.25	24.35	24.45	24.55	24.66	24.76	24.86	24.96	25.06
25.....	25.16	25.26	25.36	25.46	25.56	25.67	25.77	25.87	25.97	26.07
26.....	26.17	26.27	26.37	26.47	26.58	26.68	26.78	26.88	26.98	27.08
27.....	27.18	27.28	27.38	27.49	27.59	27.69	27.79	27.89	27.99	28.09
28.....	28.19	28.29	28.40	28.50	28.60	28.70	28.80	28.90	29.00	29.10
29.....	29.20	29.30	29.41	29.51	29.61	29.71	29.81	29.91	30.01	30.11
30.....	30.21	30.32	30.42	30.52	30.62	30.72	30.82	30.92	31.02	31.12
31.....	31.22	31.33	31.43	31.53	31.63	31.73	31.83	31.93	32.03	32.13
32.....	32.24	32.34	32.44	32.54	32.64	32.74	32.84	32.94	33.04	33.15
33.....	33.25	33.35	33.45	33.55	33.65	33.75	33.85	33.95	34.06	34.16
34.....	34.26	34.36	34.46	34.56	34.66	34.76	34.86	34.96	35.07	35.17

TABLES

TABLE XI.—DEGREES BAUMÉ CORRESPONDING TO SPECIFIC GRAVITIES AT $\frac{60^{\circ}}{60^{\circ}}$ F. $\left(\frac{15^{\circ}.56}{15^{\circ}.56} \text{ C.} \right)$
FOR LIQUIDS LIGHTER THAN WATER.

[Calculated from the formula $\text{degrees Baumé} = \frac{140}{\frac{60^\circ}{D} - 60^\circ} - 130$ which defines the Baumé scale, in general use in the United States for liquids lighter than water]

D	15 ⁵⁵⁶ 15 ⁵⁶ C.	0	1	2	3	4	5	6	7	8	9	Diff.
0.60	103.333	102.945	102.558	102.172	101.788	101.405	101.023	100.642	100.263	99.885		382
.61	99.508	99.133	98.758	98.385	98.013	97.642	97.273	96.904	96.537	96.171		370
.62	95.806	95.434	95.060	94.689	94.319	93.950	93.582	93.215	92.850	92.486		360
.63	92.222	91.870	91.519	91.169	90.820	90.472	90.126	89.780	89.436	89.092		348
.64	88.750	88.409	88.068	87.729	87.391	87.054	86.718	86.383	86.049	85.716		337
.65	85.385	85.054	84.724	84.395	84.067	83.741	83.415	83.090	82.766	82.443		327
.66	82.121	81.800	81.480	81.161	80.843	80.526	80.210	79.895	79.581	79.268		317
.67	78.955	78.644	78.333	78.024	77.715	77.407	77.101	76.795	76.490	76.186		308
.68	75.882	75.580	75.279	74.978	74.678	74.380	74.082	73.785	73.488	73.193		298
.69	72.899	72.605	72.312	72.020	71.729	71.439	71.149	70.861	70.573	70.286		290
.70	70.000	69.715	69.430	69.146	68.864	68.582	68.300	68.020	67.740	67.461		282
.71	67.183	66.906	66.629	66.354	66.078	65.804	65.531	65.258	64.986	64.715		274
.72	64.444	64.175	63.906	63.638	63.370	63.103	62.837	62.572	62.308	62.044		266
.73	61.781	61.518	61.257	60.996	60.736	60.476	60.217	59.959	59.702	59.445		260
.74	59.189	58.934	58.679	58.425	58.172	57.919	57.668	57.416	57.166	56.916		252
.75	56.667	56.418	56.170	55.923	55.676	55.430	55.185	54.941	54.697	54.455		246
.76	54.210	53.968	53.727	53.486	53.246	53.007	52.768	52.529	52.292	52.053		239
.77	51.818	51.582	51.347	51.113	50.879	50.645	50.412	50.180	49.949	49.718		234
.78	49.487	49.257	49.028	48.799	48.571	48.344	48.117	47.891	47.665	47.440		227
.79	47.215	46.991	46.768	46.545	46.322	46.101	45.879	45.659	45.439	45.219		222
.80	45.000	44.781	44.564	44.346	44.129	43.913	43.697	43.482	43.267	43.053		216
.81	42.840	42.626	42.414	42.202	41.990	41.779	41.569	41.359	41.149	40.940		210
.82	40.732	40.524	40.316	40.109	39.903	39.697	39.492	39.287	39.082	38.878		206
.83	38.675	38.472	38.269	38.067	37.866	37.665	37.464	37.264	37.064	36.866		201
.84	36.667	36.469	36.271	36.074	35.877	35.680	35.485	35.289	35.094	34.900		196
.85	34.705	34.512	34.319	34.127	33.934	33.743	33.551	33.361	33.170	32.980		192
.86	32.791	32.602	32.413	32.225	32.037	31.850	31.663	31.477	31.290	31.105		187
.87	30.920	30.735	30.550	30.366	30.183	30.000	29.817	29.635	29.453	29.272		183
.88	29.091	28.910	28.730	28.550	28.371	28.192	28.014	27.835	27.658	27.480		179
.89	27.303	27.127	26.951	26.775	26.600	26.425	26.250	26.076	25.902	25.729		175
.90	25.556	25.383	25.211	25.039	24.867	24.696	24.525	24.355	24.185	24.015		171
.91	23.846	23.677	23.509	23.341	23.173	23.005	22.838	22.672	22.506	22.339		168
.92	22.174	22.009	21.844	21.679	21.515	21.351	21.188	21.025	20.862	20.700		164
.93	20.538	20.376	20.215	20.054	19.893	19.733	19.573	19.413	19.254	19.095		160
.94	18.936	18.778	18.620	18.462	18.305	18.148	17.991	17.835	17.679	17.524		157
.95	17.368	17.214	17.059	16.905	16.751	16.597	16.444	16.290	16.138	15.985		154
.96	15.833	15.682	15.530	15.379	15.228	15.078	14.928	14.778	14.628	14.479		150
.97	14.330	14.181	14.033	13.885	13.737	13.590	13.443	13.297	13.149	13.003		147
.98	12.857	12.712	12.566	12.421	12.276	12.132	11.988	11.844	11.700	11.557		144
.99	11.414	11.271	11.129	10.987	10.845	10.704	10.562	10.421	10.281	10.140		142
1.00	10.000											

TABLES

TABLE XII — SPECIFIC GRAVITIES AT 60° F $\left(\frac{15.56}{15.56} C \right)$ CORRESPONDING TO DEGREES BAUMÉ.
FOR LIQUIDS LIGHTER THAN WATER.

[Calculated from the formula, specific gravity $\frac{60^{\circ}F.}{60^{\circ}F.} = \frac{140}{130 + \text{Deg. Baumé}}]$

Degrees Baumé	Tenths of degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
10	1.0000	0.9993	0.9986	0.9979	0.9972	0.9964	0.9957	0.9950	0.9943	0.9936
11	.9929	.9922	.9915	.9908	.9901	.9894	.9887	.9880	.9873	.9866
12	.9859	.9852	.9845	.9838	.9831	.9825	.9818	.9811	.9804	.9797
13	.9790	.9783	.9777	.9770	.9763	.9756	.9749	.9743	.9736	.9729
14	.9722	.9715	.9709	.9702	.9695	.9689	.9682	.9675	.9669	.9662
15	.9655	.9649	.9642	.9635	.9629	.9622	.9615	.9609	.9602	.9596
16	.9589	.9582	.9575	.9569	.9563	.9556	.9550	.9543	.9537	.9530
17	.9524	.9517	.9511	.9504	.9498	.9492	.9485	.9479	.9472	.9466
18	.9459	.9453	.9447	.9440	.9434	.9428	.9421	.9415	.9409	.9402
19	.9396	.9390	.9383	.9377	.9371	.9365	.9358	.9352	.9346	.9340
20	.9333	.9327	.9321	.9315	.9309	.9302	.9296	.9290	.9284	.9278
21	.9272	.9265	.9259	.9253	.9247	.9241	.9235	.9229	.9223	.9217
22	.9211	.9204	.9198	.9192	.9186	.9180	.9174	.9168	.9162	.9156
23	.9150	.9144	.9138	.9132	.9126	.9121	.9115	.9109	.9103	.9097
24	.9091	.9085	.9079	.9073	.9067	.9061	.9056	.9050	.9044	.9038
25	.9032	.9026	.9021	.9015	.9009	.9003	.8997	.8992	.8986	.8980
26	.8974	.8969	.8963	.8957	.8951	.8946	.8940	.8934	.8929	.8923
27	.8917	.8912	.8906	.8900	.8895	.8889	.8883	.8878	.8872	.8866
28	.8861	.8855	.8850	.8844	.8838	.8833	.8827	.8822	.8816	.8811
29	.8805	.8799	.8794	.8788	.8783	.8777	.8772	.8766	.8761	.8755
30	.8750	.8745	.8739	.8734	.8728	.8723	.8717	.8712	.8706	.8701
31	.8696	.8690	.8685	.8679	.8674	.8669	.8663	.8658	.8653	.8647
32	.8642	.8637	.8631	.8625	.8621	.8615	.8610	.8605	.8600	.8594
33	.8589	.8584	.8578	.8573	.8568	.8563	.8557	.8552	.8547	.8542
34	.8537	.8531	.8526	.8521	.8516	.8511	.8505	.8500	.8495	.8490
35	.8485	.8480	.8475	.8469	.8464	.8459	.8454	.8449	.8444	.8439
36	.8434	.8429	.8424	.8419	.8413	.8408	.8403	.8398	.8393	.8388
37	.8383	.8378	.8373	.8368	.8363	.8358	.8353	.8348	.8343	.8338
38	.8333	.8328	.8323	.8318	.8314	.8309	.8304	.8299	.8294	.8289
39	.8284	.8279	.8274	.8269	.8264	.8260	.8255	.8250	.8245	.8240
40	.8235	.8230	.8226	.8221	.8216	.8211	.8206	.8202	.8197	.8192
41	.8187	.8182	.8178	.8173	.8168	.8163	.8159	.8154	.8149	.8144
42	.8140	.8135	.8130	.8125	.8121	.8116	.8111	.8107	.8102	.8097
43	.8092	.8088	.8083	.8078	.8074	.8069	.8065	.8060	.8055	.8051
44	.8046	.8041	.8037	.8032	.8028	.8023	.8018	.8014	.8009	.8005
45	.8000	.7995	.7991	.7986	.7982	.7977	.7973	.7968	.7964	.7959
46	.7955	.7950	.7946	.7941	.7937	.7932	.7928	.7923	.7919	.7914
47	.7910	.7905	.7901	.7896	.7892	.7887	.7883	.7878	.7874	.7870
48	.7865	.7861	.7856	.7852	.7848	.7843	.7839	.7834	.7830	.7826
49	.7821	.7817	.7812	.7808	.7804	.7799	.7795	.7791	.7786	.7782
50	.7778	.7773	.7769	.7765	.7761	.7756	.7752	.7748	.7743	.7739
51	.7735	.7731	.7726	.7722	.7718	.7713	.7709	.7705	.7701	.7697
52	.7692	.7688	.7684	.7680	.7675	.7671	.7667	.7663	.7659	.7654
53	.7650	.7646	.7642	.7638	.7634	.7629	.7625	.7621	.7617	.7613
54	.7609	.7605	.7600	.7596	.7592	.7588	.7584	.7580	.7576	.7572
55	.7568	.7563	.7559	.7555	.7551	.7547	.7543	.7539	.7535	.7531
56	.7527	.7523	.7519	.7515	.7511	.7507	.7503	.7499	.7495	.7491
57	.7487	.7483	.7479	.7475	.7471	.7467	.7463	.7459	.7455	.7451
58	.7447	.7443	.7439	.7435	.7431	.7427	.7423	.7419	.7415	.7411
59	.7407	.7403	.7400	.7396	.7392	.7388	.7384	.7380	.7376	.7372
60	.7368	.7365	.7361	.7357	.7353	.7349	.7345	.7341	.7338	.7334
61	.7330	.7326	.7322	.7318	.7315	.7311	.7307	.7303	.7299	.7295
62	.7292	.7288	.7284	.7280	.7277	.7273	.7269	.7265	.7261	.7258
63	.7254	.7250	.7246	.7243	.7239	.7235	.7231	.7228	.7224	.7220
64	.7216	.7213	.7209	.7205	.7202	.7198	.7194	.7191	.7187	.7183
65	.7179	.7176	.7172	.7168	.7165	.7161	.7157	.7154	.7150	.7147
66	.7143	.7139	.7136	.7132	.7128	.7125	.7121	.7117	.7114	.7110
67	.7107	.7103	.7099	.7096	.7092	.7089	.7085	.7081	.7078	.7074
68	.7071	.7067	.7064	.7060	.7056	.7053	.7049	.7046	.7042	.7039
69	.7035	.7032	.7028	.7025	.7021	.7018	.7014	.7011	.7007	.7004
70	.7000	.6997	.6993	.6990	.6986	.6983	.6979	.6976	.6972	.6969
71	.6965	.6962	.6958	.6955	.6951	.6948	.6944	.6941	.6938	.6934
72	.6931	.6927	.6924	.6920	.6917	.6914	.6910	.6907	.6903	.6900
73	.6897	.6893	.6890	.6886	.6883	.6880	.6876	.6873	.6869	.6866
74	.6863	.6859	.6856	.6853	.6849	.6846	.6843	.6839	.6836	.6833
75	.6829	.6826	.6823	.6819	.6816	.6813	.6809	.6806	.6803	.6799
76	.6796	.6793	.6790	.6786	.6783	.6780	.6776	.6773	.6770	.6767
77	.6763	.6760	.6757	.6753	.6750	.6747	.6744	.6740	.6737	.6734
78	.6731	.6728	.6724	.6721	.6718	.6715	.6711	.6708	.6705	.6702
79	.6699	.6695	.6692	.6689	.6686	.6683	.6679	.6676	.6673	.6670
80	.6667	.6663	.6660	.6657	.6654	.6651	.6648	.6645	.6641	.6638
81	.6635	.6632	.6629	.6626	.6623	.6619	.6616	.6613	.6610	.6607

$$\frac{60^\circ}{60^\circ} F. \left(\frac{15^\circ.56}{15^\circ.56} C. \right)$$

FOR LIQUIDS LIGHTER THAN WATER.—*Continued.*

TABLE XIII.—DEGREES A. P. I.¹ CORRESPONDING TO SPECIFIC GRAVITIES AT $\frac{60^{\circ}}{60^{\circ}}$ F.

$$\left(\frac{15^{\circ}.56}{15^{\circ}.56} \text{ C.} \right)$$

$$\left[\text{Calculated from the formula degrees A. P. I.} = \frac{141.5}{\text{specific gravity } 60^{\circ}/60^{\circ} \text{ F.}} - 131.5 \right]$$

Sp. gr. 60°/60° F.	0	1	2	3	4	5	6	7	8	9
0.60	104.33	103.94	103.55	103.16	102.77	102.38	102.00	101.61	101.23	100.85
.61	100.47	100.09	99.71	99.33	98.96	98.58	98.21	97.84	97.46	97.09
.62	96.73	96.36	95.99	95.63	95.26	94.90	94.54	94.18	93.82	93.46
.63	93.10	92.75	92.39	92.04	91.69	91.33	90.98	90.63	90.29	89.94
.64	89.59	89.25	88.90	88.56	88.22	87.88	87.54	87.20	86.86	86.53
.65	86.19	85.86	85.52	85.19	84.86	84.53	84.20	83.87	83.55	83.22
.66	82.89	82.57	82.25	81.92	81.60	81.28	80.96	80.64	80.33	80.01
.67	79.69	79.38	79.07	78.75	78.44	78.13	77.82	77.51	77.20	76.89
.68	76.59	76.28	75.98	75.67	75.37	75.07	74.77	74.47	74.17	73.87
.69	73.57	73.28	72.98	72.68	72.39	72.10	71.80	71.51	71.22	70.93
.70	70.64	70.35	70.07	69.78	69.49	69.21	68.92	68.64	68.36	68.08
.71	67.80	67.52	67.24	66.96	66.68	66.40	66.13	65.85	65.58	65.30
.72	65.03	64.76	64.48	64.21	63.94	63.67	63.40	63.14	62.87	62.60
.73	62.34	62.07	61.81	61.54	61.28	61.02	60.76	60.49	60.23	59.97
.74	59.72	59.46	59.20	58.94	58.69	58.43	58.18	57.92	57.67	57.42
.75	57.17	56.92	56.66	56.41	56.17	55.92	55.67	55.42	55.18	54.93
.76	54.68	54.44	54.20	53.95	53.71	53.47	53.23	52.98	52.74	52.51
.77	52.27	52.03	51.79	51.55	51.32	51.08	50.85	50.61	50.38	50.14
.78	49.91	49.68	49.45	49.22	48.98	48.75	48.53	48.30	48.07	47.84
.79	47.61	47.39	47.16	46.94	46.71	46.49	46.26	46.04	45.82	45.60
.80	45.38	45.15	44.93	44.71	44.49	44.28	44.06	43.84	43.62	43.41
.81	43.19	42.98	42.76	42.55	42.33	42.12	41.91	41.69	41.48	41.27
.82	41.06	40.85	40.64	40.43	40.22	40.02	39.81	39.60	39.39	39.19
.83	38.98	38.78	38.57	38.37	38.16	37.96	37.76	37.56	37.35	37.15
.84	36.95	36.75	36.55	36.35	36.15	35.96	35.76	35.56	25.36	35.17
.85	34.97	34.77	34.58	34.39	34.19	34.00	33.80	33.61	33.42	33.23
.86	34.03	32.84	32.65	32.46	32.27	32.08	31.89	31.71	31.52	31.33
.87	31.14	30.96	30.77	30.58	30.40	30.21	30.03	29.85	29.66	29.48
.88	29.30	29.11	28.93	28.75	28.57	28.39	28.21	28.03	27.85	27.67
.89	27.49	27.31	27.13	26.95	26.78	26.60	26.42	26.25	26.07	25.90
.90	25.72	25.55	25.37	25.20	25.03	24.85	24.68	24.51	24.34	24.17
.91	23.99	23.82	23.65	23.48	23.31	23.14	22.98	22.81	22.64	22.47
.92	22.30	22.14	21.97	21.80	21.64	21.47	21.31	21.14	20.98	20.81
.93	20.65	20.49	20.32	20.16	20.00	19.84	19.68	19.51	19.35	19.19
.94	19.03	18.87	18.71	18.55	18.39	18.24	18.08	17.92	17.76	17.60
.95	17.45	17.29	17.13	16.98	16.82	16.67	16.51	16.36	16.20	16.05
.96	15.90	15.74	15.59	15.44	15.28	15.13	14.98	14.83	14.68	14.53
.97	14.38	14.23	14.08	13.93	13.78	13.63	13.48	13.33	13.18	13.04
.98	12.89	12.74	12.59	12.45	12.30	12.15	12.01	11.86	11.72	11.57
.99	11.43	11.29	11.14	11.00	10.85	10.71	10.57	10.43	10.28	10.14
1.00	10.00									

TABLES

TABLE XIV.—SPECIFIC GRAVITY AT $\frac{60^\circ}{60^\circ} + \left(\frac{15.50}{15.56} \right)$ CORRESPONDING TO DEGREES A. P. I.

[Calculated from the formula, specific gravity $\frac{60^\circ \text{F.}}{60^\circ \text{F.}} = \frac{141.5}{131.5 + \text{degrees A. P. I.}}]$

Degrees A. P. I.	Tenths of degrees									
	0	1	2	3	4	5	6	7	8	9
10	1.0000	0.9993	0.9986	0.9979	0.9972	0.9965	0.9958	0.9951	0.9944	0.9937
11	.9930	.9923	.9916	.9909	.9902	.9895	.9888	.9881	.9874	.9868
12	.9861	.9854	.9847	.9840	.9833	.9826	.9820	.9813	.9806	.9799
13	.9792	.9786	.9779	.9772	.9765	.9759	.9752	.9745	.9738	.9732
14	.9725	.9718	.9712	.9705	.9698	.9692	.9685	.9679	.9672	.9665
15	.9659	.9652	.9646	.9639	.9632	.9626	.9619	.9613	.9606	.9600
16	.9593	.9587	.9580	.9574	.9567	.9561	.9554	.9548	.9541	.9535
17	.9529	.9522	.9516	.9509	.9503	.9497	.9490	.9484	.9478	.9471
18	.9465	.9459	.9452	.9446	.9440	.9433	.9427	.9421	.9415	.9408
19	.9402	.9396	.9390	.9383	.9377	.9371	.9365	.9358	.9352	.9346
20	.9340	.9334	.9328	.9321	.9315	.9309	.9303	.9297	.9291	.9285
21	.9279	.9273	.9267	.9260	.9254	.9248	.9242	.9236	.9230	.9224
22	.9218	.9212	.9206	.9200	.9194	.9188	.9182	.9176	.9170	.9165
23	.9159	.9153	.9147	.9141	.9135	.9129	.9123	.9117	.9111	.9106
24	.9100	.9094	.9088	.9082	.9076	.9071	.9065	.9059	.9053	.9047
25	.9042	.9036	.9030	.9024	.9018	.9013	.9007	.9001	.8996	.8990
26	.8984	.8978	.8973	.8967	.8961	.8956	.8950	.8944	.8939	.8933
27	.8927	.8922	.8916	.8911	.8905	.8899	.8894	.8888	.8883	.8877
28	.8871	.8866	.8860	.8855	.8849	.8844	.8838	.8833	.8827	.8822
29	.8816	.8811	.8806	.8800	.8794	.8789	.8783	.8778	.8772	.8767
30	.8762	.8756	.8751	.8745	.8740	.8735	.8729	.8724	.8718	.8713
31	.8708	.8702	.8697	.8692	.8686	.8681	.8676	.8670	.8665	.8660
32	.8654	.8649	.8644	.8639	.8633	.8628	.8623	.8618	.8612	.8607
33	.8602	.8597	.8591	.8586	.8581	.8576	.8571	.8565	.8560	.8555
34	.8550	.8545	.8540	.8534	.8529	.8524	.8519	.8514	.8509	.8504
35	.8498	.8493	.8488	.8483	.8478	.8473	.8468	.8463	.8458	.8453
36	.8448	.8443	.8438	.8433	.8428	.8423	.8418	.8413	.8408	.8403
37	.8398	.8393	.8388	.8383	.8378	.8373	.8368	.8363	.8358	.8353
38	.8348	.8343	.8338	.8333	.8328	.8324	.8319	.8314	.8309	.8304
39	.8299	.8294	.8289	.8285	.8280	.8275	.8270	.8265	.8260	.8256
40	.8251	.8246	.8241	.8236	.8232	.8227	.8222	.8217	.8212	.8208
41	.8203	.8198	.8193	.8189	.8184	.8179	.8174	.8170	.8165	.8160
42	.8155	.8151	.8146	.8142	.8137	.8132	.8128	.8123	.8118	.8114
43	.8109	.8104	.8100	.8095	.8090	.8086	.8081	.8076	.8072	.8067
44	.8063	.8058	.8054	.8049	.8044	.8040	.8035	.8031	.8026	.8022
45	.8017	.8012	.8008	.8003	.7999	.7994	.7990	.7985	.7981	.7976
46	.7972	.7967	.7963	.7958	.7954	.7949	.7945	.7941	.7936	.7932
47	.7927	.7923	.7918	.7914	.7909	.7905	.7901	.7896	.7892	.7887
48	.7883	.7879	.7874	.7870	.7865	.7861	.7857	.7853	.7848	.7844
49	.7839	.7835	.7831	.7826	.7822	.7818	.7813	.7809	.7805	.7800
50	.7796	.7792	.7788	.7783	.7779	.7775	.7770	.7766	.7762	.7758
51	.7753	.7749	.7745	.7741	.7736	.7732	.7728	.7724	.7720	.7715
52	.7711	.7707	.7703	.7699	.7694	.7690	.7686	.7682	.7678	.7674
53	.7669	.7665	.7661	.7657	.7653	.7649	.7645	.7640	.7636	.7632
54	.7628	.7624	.7620	.7616	.7612	.7608	.7603	.7599	.7595	.7591
55	.7587	.7583	.7579	.7575	.7571	.7567	.7563	.7559	.7555	.7551
56	.7547	.7543	.7539	.7535	.7531	.7527	.7523	.7519	.7515	.7511
57	.7507	.7503	.7499	.7495	.7491	.7487	.7483	.7479	.7475	.7471
58	.7467	.7463	.7459	.7455	.7451	.7447	.7443	.7440	.7436	.7432
59	.7428	.7424	.7420	.7416	.7412	.7408	.7405	.7401	.7397	.7393
60	.7389	.7385	.7381	.7377	.7374	.7370	.7366	.7362	.7358	.7354
61	.7351	.7347	.7343	.7339	.7335	.7332	.7328	.7324	.7320	.7316
62	.7313	.7309	.7305	.7301	.7298	.7294	.7290	.7286	.7283	.7279
63	.7275	.7271	.7268	.7264	.7260	.7256	.7253	.7249	.7245	.7242
64	.7238	.7234	.7230	.7227	.7223	.7219	.7216	.7212	.7208	.7205
65	.7201	.7197	.7194	.7190	.7186	.7183	.7179	.7175	.7172	.7168
66	.7165	.7161	.7157	.7154	.7150	.7146	.7143	.7139	.7136	.7132
67	.7128	.7125	.7121	.7118	.7114	.7111	.7107	.7103	.7100	.7096
68	.7093	.7089	.7086	.7082	.7079	.7075	.7071	.7068	.7064	.7061
69	.7057	.7054	.7050	.7047	.7043	.7040	.7036	.7033	.7029	.7026
70	.7022	.7019	.7015	.7012	.7008	.7005	.7001	.6998	.6995	.6991
71	.6988	.6984	.6981	.6977	.6974	.6970	.6967	.6964	.6960	.6957
72	.6953	.6950	.6946	.6943	.6940	.6936	.6933	.6929	.6926	.6923
73	.6919	.6916	.6913	.6909	.6906	.6902	.6899	.6896	.6892	.6889
74	.6886	.6882	.6879	.6876	.6872	.6869	.6866	.6862	.6859	.6856
75	.6852	.6849	.6846	.6842	.6839	.6836	.6832	.6829	.6826	.6823
76	.6819	.6816	.6813	.6809	.6806	.6803	.6800	.6796	.6793	.6790
77	.6787	.6783	.6780	.6777	.6774	.6770	.6767	.6764	.6761	.6757
78	.6754	.6751	.6748	.6745	.6741	.6738	.6735	.6732	.6728	.6725
79	.6722	.6719	.6716	.6713	.6709	.6706	.6703	.6700	.6697	.6693
80	.6690	.6687	.6684	.6681	.6678	.6675	.6671	.6668	.6665	.6662

TABLES

TABLE XIV.—SPECIFIC GRAVITY AT $\frac{60^{\circ}}{60^{\circ}} \text{ F. } \left(\frac{15^{\circ}.56}{15^{\circ}.56} \text{ C. } \right)$ CORRESPONDING TO DEGREES A. P. I.—
Continued.

[illegible]

TABLES

TABLE XV.—DEGREES A. P. I. (MODULUS 141.5) CORRESPONDING TO DEGREES BAUMÉ (MODULUS 140), PETROLEUM OILS.

(Extract from Table 6, Circular of the Bureau of Standards, No. 154)

Degrees Baume (modulus 140)	Tenths of degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
10.	10.00	10.10	10.20	10.30	10.40	10.51	10.61	10.71	10.81	10.91
11.	11.01	11.11	11.21	11.31	11.42	11.52	11.62	11.72	11.82	11.92
12.	12.02	12.12	12.22	12.32	12.43	12.53	12.63	12.73	12.83	12.93
13.	13.03	13.13	13.23	13.34	13.44	13.54	13.64	13.74	13.84	13.94
14.	14.04	14.14	14.24	14.35	14.45	14.55	14.65	14.75	14.85	14.95
15.	15.05	15.15	15.26	15.36	15.46	15.56	15.66	15.76	15.86	15.96
16.	16.06	16.17	16.27	16.37	16.47	16.57	16.67	16.77	16.87	16.97
17.	17.08	17.18	17.28	17.38	17.48	17.58	17.68	17.78	17.88	17.98
18.	18.09	18.19	18.29	18.40	18.49	18.59	18.69	18.79	18.89	19.00
19.	19.10	19.20	19.30	19.40	19.50	19.60	19.70	19.80	19.90	20.01
20.	20.11	20.21	20.31	20.41	20.51	20.61	20.71	20.81	20.92	21.02
21.	21.12	21.22	21.32	21.42	21.52	21.62	21.72	21.83	21.93	22.03
22.	22.13	22.23	22.33	22.43	22.53	22.63	22.74	22.84	22.94	23.04
23.	23.14	23.24	23.34	23.44	23.54	23.64	23.75	23.85	23.95	24.05
24.	24.15	24.25	24.35	24.45	24.55	24.66	24.76	24.86	24.96	25.06
25.	25.16	25.26	25.36	25.46	25.56	25.67	25.77	25.87	25.97	26.07
26.	26.17	26.27	26.37	26.47	26.58	26.68	26.78	26.88	26.98	27.08
27.	27.18	27.28	27.38	27.49	27.59	27.69	27.79	27.89	27.99	28.09
28.	28.19	28.29	28.40	28.50	28.60	28.70	28.80	28.90	29.00	29.10
29.	29.20	29.30	29.41	29.51	29.61	29.71	29.81	29.91	30.01	30.11
30.	30.21	30.32	30.42	30.52	30.62	30.72	30.82	30.92	31.02	31.12
31.	31.22	31.33	31.43	31.53	31.63	31.73	31.83	31.93	32.03	32.13
32.	32.24	32.34	32.44	32.54	32.64	32.74	32.84	32.94	33.04	33.15
33.	33.25	33.35	33.45	33.55	33.65	33.75	33.85	33.95	34.06	34.16
34.	34.26	34.36	34.46	34.56	34.66	34.76	34.86	34.96	35.07	35.17
35.	35.27	35.37	35.47	35.57	35.67	35.77	35.87	35.98	36.08	36.18
36.	36.28	36.38	36.48	36.58	36.68	36.78	36.88	36.99	37.09	37.19
37.	37.29	37.39	37.49	37.59	37.69	37.79	37.90	38.00	38.10	38.20
38.	38.30	38.40	38.50	38.60	38.70	38.81	38.91	39.01	39.11	39.21
39.	39.31	39.41	39.51	39.61	39.72	39.82	39.92	40.02	40.12	40.22
40.	40.32	40.42	40.52	40.62	40.73	40.83	40.93	41.03	41.13	41.23
41.	41.33	41.43	41.53	41.64	41.74	41.84	41.94	42.04	42.14	42.24
42.	42.34	42.44	42.54	42.65	42.75	42.85	42.95	43.05	43.15	43.25
43.	43.35	43.45	43.56	43.66	43.76	43.86	43.96	44.06	44.16	44.26
44.	44.36	44.47	44.57	44.67	44.77	44.87	44.97	45.07	45.17	45.27
45.	45.38	45.48	45.58	45.68	45.78	45.88	45.98	46.08	46.18	46.28
46.	46.39	46.49	46.59	46.69	46.79	46.89	46.99	47.09	47.19	47.30
47.	47.40	47.50	47.60	47.70	47.80	47.90	48.00	48.10	48.20	48.31
48.	48.41	48.51	48.61	48.71	48.81	48.91	49.01	49.11	49.22	49.32
49.	49.42	49.52	49.62	49.72	49.82	49.92	50.02	50.13	50.23	50.33
50.	50.43	50.53	50.63	50.73	50.83	50.93	51.04	51.14	51.24	51.34
51.	51.44	51.54	51.64	51.74	51.84	51.94	52.05	52.15	52.25	52.35
52.	52.45	52.55	52.65	52.75	52.85	52.96	53.06	53.16	53.26	53.36
53.	53.46	53.56	53.66	53.76	53.86	53.97	54.07	54.17	54.27	54.37
54.	54.47	54.57	54.67	54.77	54.88	54.98	55.08	55.18	55.28	55.38
55.	55.48	55.58	55.68	55.79	55.89	55.99	56.09	56.19	56.29	56.39
56.	56.49	56.59	56.70	56.80	56.90	57.00	57.10	57.20	57.30	57.40
57.	57.50	57.60	57.71	57.81	57.91	58.01	58.11	58.21	58.31	58.41
58.	58.51	58.62	58.72	58.82	58.92	59.02	59.12	59.22	59.32	59.42
59.	59.52	59.63	59.73	59.83	59.93	60.03	60.13	60.23	60.33	60.43
60.	60.54	60.64	60.74	60.84	60.94	61.04	61.14	61.24	61.34	61.45
61.	61.55	61.65	61.75	61.85	61.95	62.05	62.15	62.25	62.36	62.46
62.	62.56	62.66	62.76	62.86	62.96	63.06	63.16	63.26	63.37	63.47
63.	63.57	63.67	63.77	63.87	63.97	64.07	64.17	64.28	64.38	64.48
64.	64.58	64.68	64.78	64.88	64.98	65.08	65.18	65.29	65.39	65.49
65.	65.59	65.69	65.79	65.89	65.99	66.09	66.20	66.30	66.40	66.50
66.	66.60	66.70	66.80	66.90	67.00	67.11	67.21	67.31	67.41	67.51
67.	67.61	67.71	67.81	67.91	68.02	68.12	68.22	68.32	68.42	68.52
68.	68.62	68.72	68.82	68.92	69.03	69.13	69.23	69.33	69.43	69.53
69.	69.63	69.73	69.83	69.94	70.04	70.14	70.24	70.34	70.44	70.54
70.	70.64	70.74	70.84	70.95	71.05	71.15	71.25	71.35	71.45	71.55
71.	71.65	71.75	71.86	71.96	72.06	72.16	72.26	72.36	72.46	72.56
72.	72.66	72.77	72.87	72.97	73.07	73.17	73.27	73.37	73.47	73.57
73.	73.68	73.78	73.88	73.98	74.08	74.18	74.28	74.38	74.48	74.58
74.	74.69	74.79	74.89	74.99	75.09	75.19	75.29	75.39	75.49	75.60

TABLES

TABLE XVI.—VOLUME AT 60° F. OCCUPIED BY UNIT VOLUME AT INDICATED TEMPERATURE.

Observed temperature in °F.	Degrees A. P. I. at 60° F.									
	10	11	12	13	14	15	16	17	18	19
	Volume at 60° F. occupied by unit volume at indicated temperature									
30.....	1.0111	1.0112	1.0113	1.0113	1.0114	1.0115	1.0116	1.0117	1.0117	1.0118
31.....	1.0107	1.0108	1.0109	1.0109	1.0110	1.0111	1.0112	1.0113	1.0113	1.0114
32.....	1.0103	1.0104	1.0105	1.0105	1.0106	1.0107	1.0108	1.0109	1.0109	1.0110
33.....	1.0100	1.0101	1.0101	1.0102	1.0102	1.0103	1.0104	1.0105	1.0105	1.0106
34.....	1.0096	1.0097	1.0097	1.0098	1.0098	1.0099	1.0100	1.0101	1.0101	1.0102
35.....	1.0092	1.0093	1.0093	1.0094	1.0095	1.0095	1.0096	1.0097	1.0097	1.0098
36.....	1.0088	1.0089	1.0089	1.0090	1.0090	1.0091	1.0092	1.0093	1.0093	1.0094
37.....	1.0084	1.0085	1.0085	1.0086	1.0086	1.0087	1.0088	1.0089	1.0089	1.0090
38.....	1.0081	1.0082	1.0082	1.0083	1.0083	1.0084	1.0085	1.0085	1.0086	1.0086
39.....	1.0077	1.0078	1.0078	1.0079	1.0079	1.0080	1.0081	1.0081	1.0082	1.0082
40.....	1.0073	1.0074	1.0074	1.0075	1.0075	1.0076	1.0077	1.0077	1.0078	1.0078
41.....	1.0069	1.0070	1.0070	1.0071	1.0071	1.0072	1.0073	1.0073	1.0074	1.0074
42.....	1.0066	1.0066	1.0067	1.0067	1.0068	1.0068	1.0069	1.0069	1.0070	1.0070
43.....	1.0062	1.0063	1.0063	1.0064	1.0064	1.0065	1.0065	1.0066	1.0066	1.0067
44.....	1.0059	1.0059	1.0060	1.0060	1.0061	1.0061	1.0061	1.0062	1.0062	1.0063
45.....	1.0055	1.0055	1.0056	1.0056	1.0057	1.0057	1.0057	1.0058	1.0058	1.0059
46.....	1.0051	1.0051	1.0052	1.0052	1.0053	1.0053	1.0053	1.0054	1.0054	1.0055
47.....	1.0048	1.0048	1.0048	1.0049	1.0049	1.0049	1.0049	1.0050	1.0050	1.0051
48.....	1.0044	1.0044	1.0045	1.0045	1.0046	1.0046	1.0046	1.0046	1.0047	1.0047
49.....	1.0041	1.0041	1.0041	1.0042	1.0042	1.0042	1.0042	1.0042	1.0043	1.0043
50.....	1.0037	1.0037	1.0037	1.0038	1.0038	1.0038	1.0038	1.0038	1.0039	1.0039
51.....	1.0033	1.0033	1.0033	1.0034	1.0034	1.0034	1.0034	1.0034	1.0035	1.0035
52.....	1.0029	1.0029	1.0029	1.0030	1.0030	1.0030	1.0030	1.0030	1.0031	1.0031
53.....	1.0026	1.0026	1.0026	1.0027	1.0027	1.0027	1.0027	1.0027	1.0028	1.0028
54.....	1.0022	1.0022	1.0022	1.0023	1.0023	1.0023	1.0023	1.0023	1.0024	1.0024
55.....	1.0018	1.0018	1.0018	1.0019	1.0019	1.0019	1.0019	1.0019	1.0020	1.0020
56.....	1.0014	1.0014	1.0014	1.0015	1.0015	1.0015	1.0015	1.0015	1.0016	1.0016
57.....	1.0011	1.0011	1.0011	1.0011	1.0011	1.0011	1.0011	1.0011	1.0012	1.0012
58.....	1.0007	1.0007	1.0007	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008
59.....	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004
60.....	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
61.....	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996
62.....	.9993	.9993	.9993	.9992	.9992	.9992	.9992	.9992	.9992	.9992
63.....	.9989	.9989	.9989	.9989	.9989	.9989	.9989	.9989	.9988	.9988
64.....	.9986	.9986	.9986	.9985	.9985	.9985	.9985	.9985	.9984	.9984
65.....	.9982	.9982	.9982	.9981	.9981	.9981	.9981	.9981	.9980	.9980
66.....	.9978	.9978	.9978	.9977	.9977	.9977	.9977	.9977	.9976	.9976
67.....	.9975	.9975	.9974	.9974	.9973	.9973	.9973	.9973	.9972	.9972
68.....	.9971	.9971	.9971	.9970	.9970	.9970	.9970	.9970	.9969	.9969
69.....	.9968	.9968	.9967	.9967	.9966	.9966	.9966	.9966	.9965	.9965
70.....	.9964	.9964	.9963	.9963	.9962	.9962	.9962	.9962	.9961	.9961
71.....	.9960	.9960	.9959	.9959	.9958	.9958	.9958	.9958	.9957	.9957
72.....	.9957	.9956	.9956	.9955	.9955	.9954	.9954	.9954	.9953	.9953
73.....	.9953	.9953	.9952	.9952	.9951	.9951	.9951	.9950	.9950	.9949
74.....	.9950	.9949	.9949	.9948	.9948	.9947	.9947	.9946	.9946	.9945
75.....	.9946	.9945	.9945	.9944	.9944	.9943	.9943	.9942	.9942	.9941
76.....	.9942	.9941	.9941	.9940	.9940	.9939	.9939	.9938	.9938	.9937
77.....	.9939	.9938	.9938	.9937	.9937	.9936	.9936	.9935	.9934	.9934
78.....	.9935	.9934	.9934	.9933	.9933	.9932	.9932	.9931	.9931	.9930
79.....	.9932	.9931	.9931	.9930	.9930	.9929	.9928	.9928	.9927	.9927
80.....	.9928	.9927	.9927	.9926	.9926	.9925	.9924	.9924	.9923	.9923
81.....	.9924	.9923	.9923	.9922	.9922	.9921	.9920	.9920	.9919	.9919
82.....	.9921	.9920	.9919	.9919	.9918	.9917	.9916	.9916	.9915	.9915
83.....	.9917	.9916	.9916	.9915	.9915	.9914	.9913	.9912	.9912	.9911
84.....	.9914	.9913	.9912	.9912	.9911	.9910	.9909	.9908	.9908	.9907
85.....	.9910	.9909	.9908	.9908	.9907	.9906	.9905	.9904	.9904	.9903
86.....	.9906	.9905	.9904	.9904	.9903	.9902	.9901	.9900	.9900	.9899
87.....	.9903	.9902	.9901	.9900	.9899	.9898	.9897	.9896	.9896	.9895
88.....	.9899	.9898	.9897	.9897	.9896	.9895	.9894	.9893	.9893	.9892
89.....	.9896	.9895	.9894	.9893	.9892	.9891	.9890	.9889	.9889	.9888
90.....	.9892	.9891	.9890	.9889	.9888	.9887	.9886	.9885	.9885	.9884
91.....	.9888	.9887	.9886	.9885	.9884	.9883	.9882	.9881	.9881	.9880
92.....	.9885	.9884	.9883	.9881	.9880	.9879	.9878	.9877	.9877	.9876
93.....	.9881	.9880	.9879	.9878	.9877	.9876	.9875	.9874	.9873	.9872
94.....	.9873	.9877	.9876	.9874	.9873	.9872	.9871	.9870	.9869	.9868

TABLE XVI.—VOLUME AT 60° F. OCCUPIED BY UNIT VOLUME AT INDICATED TEMPERATURE.—
(continued)

Observed temperature in ° F.	Degrees A. P. I. at 60° F.									
	10	11	12	13	14	15	16	17	18	19
	Volume at 60° F. occupied by unit volume at indicated temperature									
95	.9874	.9873	.9872	.9870	.9869	.9868	.9867	.9866	.9865	.9864
96	.9870	.9869	.9868	.9866	.9865	.9864	.9863	.9862	.9861	.9860
97	.9867	.9866	.9865	.9863	.9862	.9861	.9860	.9859	.9857	.9856
98	.9863	.9862	.9861	.9859	.9858	.9857	.9856	.9855	.9854	.9853
99	.9860	.9859	.9858	.9856	.9855	.9854	.9853	.9852	.9850	.9849
100	.9856	.9855	.9854	.9852	.9851	.9850	.9849	.9848	.9846	.9845
101	.9852	.9851	.9850	.9848	.9847	.9846	.9845	.9844	.9842	.9841
102	.9849	.9848	.9846	.9845	.9843	.9842	.9841	.9840	.9838	.9837
103	.9845	.9844	.9843	.9841	.9840	.9839	.9838	.9837	.9835	.9834
104	.9842	.9841	.9839	.9838	.9836	.9835	.9834	.9833	.9831	.9830
105	.9838	.9837	.9835	.9834	.9832	.9831	.9830	.9829	.9827	.9826
106	.9834	.9833	.9831	.9830	.9828	.9827	.9826	.9825	.9823	.9822
107	.9831	.9830	.9828	.9827	.9825	.9824	.9823	.9821	.9820	.9818
108	.9827	.9826	.9824	.9823	.9821	.9820	.9819	.9818	.9816	.9815
109	.9824	.9823	.9821	.9820	.9818	.9817	.9816	.9814	.9813	.9811
110	.9820	.9819	.9817	.9816	.9814	.9813	.9812	.9810	.9809	.9807
111	.9816	.9815	.9813	.9812	.9810	.9809	.9808	.9806	.9805	.9803
112	.9813	.9811	.9810	.9808	.9807	.9805	.9804	.9802	.9801	.9799
113	.9809	.9808	.9806	.9805	.9803	.9802	.9800	.9799	.9797	.9796
114	.9806	.9804	.9803	.9801	.9800	.9798	.9796	.9795	.9793	.9792
115	.9802	.9800	.9799	.9797	.9796	.9794	.9792	.9791	.9789	.9788
116	.9797	.9797	.9795	.9794	.9792	.9790	.9788	.9787	.9785	.9784
117	.9795	.9793	.9792	.9790	.9789	.9787	.9785	.9783	.9782	.9780
118	.9792	.9790	.9788	.9787	.9785	.9783	.9781	.9780	.9778	.9777
119	.9788	.9786	.9785	.9783	.9782	.9780	.9778	.9776	.9775	.9773

[illegible]

TABLES

TABLE XVI.—VOLUME AT 60° F. OCCUPIED BY UNIT VOLUME AT INDICATED TEMPERATURE.—
Continued.

Observed temperature in °F.	Degrees A. P. I. at 60° F.									
	20	21	22	23	24	25	26	27	28	29
	Volume at 60° F. occupied by unit volume at indicated temperature									
60	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
61	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996	.9996
62	.9992	.9992	.9992	.9992	.9992	.9992	.9992	.9992	.9992	.9992
63	.9988	.9988	.9988	.9988	.9988	.9988	.9988	.9987	.9987	.9987
64	.9984	.9984	.9984	.9984	.9984	.9984	.9984	.9983	.9983	.9983
65	.9980	.9980	.9980	.9980	.9980	.9980	.9980	.9979	.9979	.9979
66	.9976	.9976	.9976	.9976	.9976	.9976	.9976	.9975	.9975	.9975
67	.9972	.9972	.9972	.9972	.9972	.9972	.9972	.9971	.9971	.9971
68	.9969	.9969	.9968	.9968	.9968	.9967	.9967	.9966	.9966	.9966
69	.9965	.9965	.9964	.9964	.9964	.9963	.9963	.9962	.9962	.9962
70	.9961	.9961	.9960	.9960	.9960	.9959	.9959	.9958	.9958	.9958
71	.9957	.9957	.9956	.9956	.9956	.9955	.9955	.9954	.9954	.9954
72	.9953	.9953	.9952	.9952	.9952	.9951	.9951	.9950	.9950	.9950
73	.9949	.9949	.9948	.9948	.9948	.9947	.9947	.9946	.9946	.9946
74	.9945	.9945	.9944	.9944	.9944	.9943	.9943	.9942	.9942	.9942
75	.9941	.9941	.9940	.9940	.9940	.9939	.9939	.9938	.9938	.9938
76	.9937	.9937	.9936	.9936	.9936	.9935	.9935	.9934	.9934	.9934
77	.9933	.9933	.9932	.9932	.9932	.9931	.9931	.9930	.9930	.9929
78	.9930	.9929	.9929	.9928	.9928	.9927	.9926	.9926	.9925	.9925
79	.9926	.9925	.9925	.9924	.9924	.9923	.9922	.9922	.9921	.9920
80	.9922	.9921	.9921	.9920	.9920	.9919	.9918	.9918	.9917	.9916
81	.9918	.9917	.9917	.9916	.9916	.9915	.9914	.9914	.9913	.9912
82	.9914	.9913	.9913	.9912	.9912	.9911	.9910	.9910	.9909	.9908
83	.9910	.9909	.9909	.9908	.9908	.9907	.9906	.9905	.9904	.9903
84	.9906	.9905	.9905	.9904	.9904	.9903	.9902	.9901	.9900	.9899
85	.9902	.9901	.9901	.9900	.9900	.9899	.9898	.9897	.9896	.9895
86	.9898	.9897	.9897	.9896	.9896	.9895	.9894	.9893	.9892	.9891
87	.9894	.9893	.9893	.9892	.9892	.9891	.9890	.9889	.9888	.9887
88	.9891	.9890	.9889	.9888	.9887	.9886	.9885	.9884	.9883	.9882
89	.9887	.9886	.9885	.9884	.9883	.9882	.9881	.9880	.9879	.9878
90	.9883	.9882	.9881	.9880	.9879	.9878	.9877	.9876	.9875	.9874
91	.9879	.9878	.9877	.9876	.9875	.9874	.9873	.9872	.9871	.9870
92	.9875	.9874	.9873	.9872	.9871	.9870	.9869	.9868	.9867	.9866
93	.9871	.9870	.9869	.9868	.9867	.9866	.9865	.9864	.9863	.9862
94	.9867	.9866	.9865	.9864	.9863	.9862	.9861	.9860	.9859	.9858
95	.9863	.9862	.9861	.9860	.9859	.9858	.9857	.9856	.9855	.9854
96	.9859	.9858	.9857	.9856	.9855	.9854	.9853	.9852	.9851	.9850
97	.9855	.9854	.9853	.9852	.9851	.9850	.9849	.9848	.9847	.9846
98	.9852	.9851	.9849	.9848	.9847	.9846	.9845	.9843	.9842	.9841
99	.9848	.9847	.9845	.9844	.9843	.9842	.9841	.9839	.9838	.9837
100	.9844	.9843	.9841	.9840	.9839	.9838	.9837	.9835	.9834	.9833
101	.9840	.9839	.9837	.9836	.9835	.9834	.9833	.9831	.9830	.9829
102	.9836	.9835	.9833	.9832	.9831	.9830	.9829	.9827	.9826	.9825
103	.9833	.9832	.9830	.9829	.9828	.9826	.9824	.9823	.9821	.9820
104	.9829	.9828	.9826	.9825	.9824	.9822	.9820	.9819	.9817	.9816
105	.9825	.9824	.9822	.9821	.9820	.9818	.9816	.9815	.9813	.9812
106	.9821	.9820	.9818	.9817	.9816	.9814	.9812	.9811	.9809	.9808
107	.9817	.9816	.9814	.9813	.9812	.9810	.9808	.9807	.9805	.9804
108	.9814	.9812	.9811	.9809	.9808	.9806	.9804	.9803	.9801	.9799
109	.9810	.9808	.9807	.9805	.9804	.9802	.9800	.9799	.9797	.9795
110	.9806	.9804	.9803	.9801	.9800	.9798	.9796	.9795	.9793	.9791
111	.9802	.9800	.9799	.9797	.9796	.9794	.9792	.9791	.9789	.9787
112	.9798	.9796	.9795	.9793	.9792	.9790	.9788	.9787	.9785	.9783
113	.9794	.9792	.9791	.9789	.9788	.9786	.9784	.9782	.9780	.9778
114	.9790	.9788	.9787	.9785	.9784	.9782	.9780	.9778	.9776	.9774
115	.9786	.9784	.9783	.9781	.9780	.9778	.9776	.9774	.9772	.9770
116	.9782	.9780	.9778	.9777	.9776	.9774	.9772	.9770	.9768	.9766
117	.9778	.9776	.9775	.9773	.9772	.9770	.9768	.9766	.9764	.9762
118	.9775	.9773	.9771	.9769	.9768	.9766	.9764	.9761	.9759	.9757
119	.9771	.9769	.9767	.9765	.9764	.9762	.9760	.9757	.9755	.9753

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